TASK FORCE HYDRO

NUCLEAR POWER IN ONTARIO

REPORT NUMBER THREE

Established by
the Committee on
Government Productivity
of Ontario.

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REPORT NUMBER THREE

REPORT TO THE EXECUTIVE COUNCIL

NUCLEAR POWER IN ONTARIO

Presented to the Executive Council
16 February, 1973

ONTARIO

COMMITTEE ON GOVERNMENT PRODUCTIVITY

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TO HIS HONOUR

THE LIEUTENANT-GOVERNOR OF THE PROVINCE OF ONTARIO

MAY IT PLEASE YOUR HONOUR

We, the members of the Committee on Government Productivity, appointed by Order-in-Council, dated 23rd December, 1969, to inquire into all matters pertaining to the management of the Government of Ontario and requested in the Speech from the Throne dated 30th March, 1971, to review the function, structure, operation, financing and objectives of the Hydro-Electric Power Commission of Ontario, herewith submit for your consideration a third report of Task Force Hydro containing their recommendations relating to Nuclear Power in Ontario.

John Kenyon
Chairman

February, 1973

TASK
FORCE
HYDRO

Established
by the Committee
on Government
Productivity of
Ontario

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TO JOHN B. CRONYN, ESQ.

CHAIRMAN OF THE COMMITTEE
ON GOVERNMENT PRODUCTIVITY

We, the members of the Steering Committee of Task Force Hydro, appointed by the Government of Ontario to review the function, structure, operation, financing and objectives of The Hydro-Electric Power Commission of Ontario, submit herewith a third report containing recommendations relating to Nuclear Power in Ontario.

Hugh Crothers
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J. D. MUNCASTER
CHAIRMAN

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

FOREWORD

Task Force Hydro was established to examine major issues associated with the future development of Ontario Hydro. No such investigation could ignore the central role that nuclear power will play in the expansion of present generating capacity. The high capital cost of Canada's CANDU reactor has been one of the concerns in the controversy surrounding Ontario Hydro's decision to proceed with the Canadian heavy water series of reactors in the late 1950's. While the recent outstanding performance of the Pickering nuclear generating station has allayed many of the earlier fears over Ontario Hydro's choice, the continuing shortage of heavy water, the escalation of costs and the absence of orders from other countries, have left lingering doubts as to whether future decisions regarding nuclear plants should follow past policies.

In this report we air these and other concerns, assess the background and potential of the CANDU systems and, on the basis of evidence available at the present time, examine the merits of alternative nuclear generating systems. Discussions held with persons associated with nuclear power in Ontario and the rest of Canada, visits to the United States, the United Kingdom and France, and a variety of published reports and documents have provided the background material for our study.

The development of the CANDU family of heavy water reactors by Ontario Hydro and A.E.C.L. represents an outstanding achievement for Canadian technology. CANDU is distinctly Canadian and potentially could contribute greater benefit to Canada than any Canadian technical development of comparable magnitude. Success to date stems from three important factors, the first of which is the efficiency of heavy water as a moderator. Secondly, the inherent qualities of the pressure tube concept allow on-power refuelling and increased flexibility in design. Perhaps the most important contribution to the program however has come through the effective melding of A.E.C.L.'s research and development capability with Ontario Hydro's engineering talent.

In spite of the success already achieved, the program is currently going through a critical stage which requires short-run but nevertheless vitally important problems to be solved. In our view the most pressing immediate concern is the adequate supply of heavy water. Great efforts are being put forward but the ability to produce at planned capacity remains to be proven. We see the possibility of a world shortage of uranium which suggests that consideration be given to controlling exports to the point where domestic supplies are assured and where surpluses can be used to increase the attractiveness of CANDU in world markets. There is also an urgent need to increase exploration to find new reserves.

American reactors dominate the nuclear power scene in the western world outside of the United States. No other country appears capable of developing its own nuclear power system unless it can rely on foreign sales. We therefore feel that the greatest challenge ahead is the development of overseas markets for CANDU reactors. This will require:

- the redoubling of sales effort to include international marketing expertise from Government and industry.

- the stimulation of domestic sales to increase the competence of Canadian industry and to reduce manufacturing costs.

- a continuing program of research and development to exploit the inherent technical qualities of CANDU reactors.

And finally, Task Force Hydro sees the need for a continuing effort to publicize CANDU in order to acquaint Canadians with the problems ahead including the need to prove performance through further operating experience, and to explain the great potential benefits which could come through continuing efforts to exploit our accomplishment.

SECTION I

DECISIONS ON NUCLEAR POWER – PAST AND PRESENT

Current projections visualize an annual increase in the demand for electrical energy in Ontario of 7 percent until 1985, and from 5 to 6 percent to the end of the century.

Within this context it is reported that 12 percent of the electrical generating system of Ontario Hydro is currently based on nuclear energy, 44% on hydraulic and 44% on thermal, fossil-fuel energy (coal, oil, etc.). This will change radically by the end of the present decade with the hydroelectric capacity, as a proportion of the total, declining and thermal, including nuclear, increasing. The flexibility of electrical power output that can be achieved by using a mixture of generating stations based on different sources of power is important if the variations in daily and seasonal requirements are to be accommodated. With technology in its present state, nuclear power stations minimize the cost of energy when operated at a high capacity factor; because of their high capital cost and low fuelling cost they are particularly suited to satisfying base load rather than peak demand. Variations in demand can better be met from hydraulic and fossil-fuelled plants. The decision as to whether or not reliance should continue to be placed on a single basic type of nuclear power station, in order to further optimize availability, will be given careful consideration.

The estimated installed world nuclear power capacity in 1975 will be 100,000 megawatts (MW). By 1990 this total will have risen to 1,330,000 MW of which almost 500,000 will be installed in the United States and 35,000 in Canada. Such an increase, 13-fold over a 15 year period demonstrates a confidence shared by virtually all industralized nations in the future of nuclear power. However, it should be stressed, there are difficult decisions ahead. Costs and environmental issues for example, are particularly intransigent because of so many unknown and unpredictable factors. The rapidly changing state of nuclear technology with concomitant pressures to introduce design improvements, the presently accepted useful life of 25 to 30 years for a nuclear generating station, and the lead time of 7 to 10 years required to place a station, once committed, in service–all combine to make decision making extremely difficult and complex, especially when we are faced with such an explosive rate of expansion.

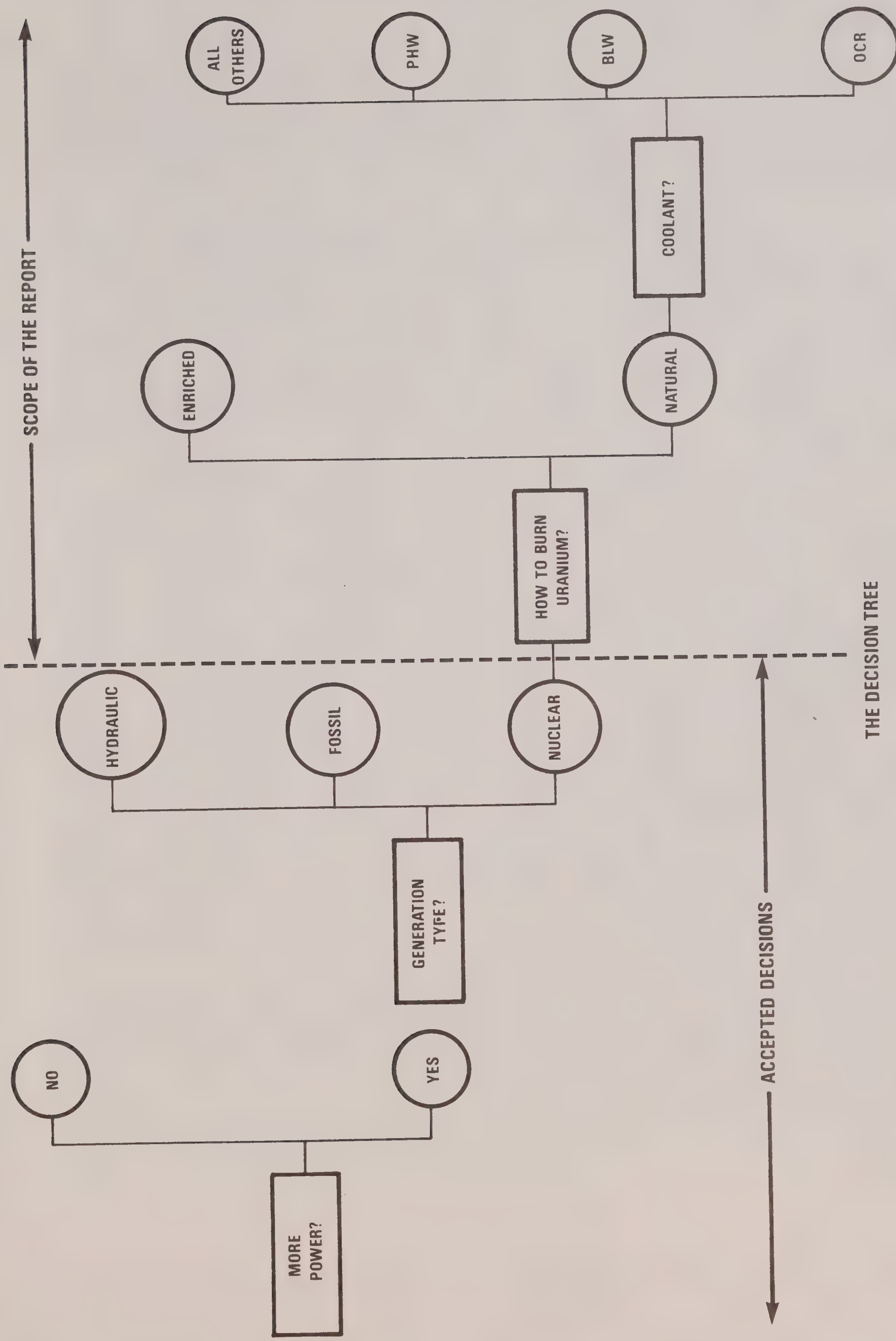
Once a decision to increase the generating capacity has been made, the next general issue is to determine how the increased demand can best be satisfied–nuclear, hydraulic, or conventional thermal for example. The one alternative, to increase the nuclear component, leads to a further set of decisions: what form of uranium (natural or enriched), what moderator (heavy water, graphite, light water, etc.) and what coolant (light water, heavy water, liquid metal, etc.)? These alternatives are illustrated in Figure 1 by a "deci-

sion tree". Decisions taken in the past resulted in the construction of the Pickering Nuclear Generating Station and the commitment to build the Bruce Generating Station. What of future decisions?

For this study we have accepted the projected growth in demand for electrical power and the fact that Ontario Hydro will increase its capacity in response to this demand. In addition, we have assumed that a part of this increased capacity will be satisfied by nuclear generating stations. Our study starts from this point, debating the major issues which arise from the questions of what fuel to burn, and what coolant to introduce but always bearing in mind the objective for Ontario Hydro recommended in Report Number One[1] to the effect that Ontario Hydro supply electric power to the people of Ontario at the lowest feasible cost, consistent with financial soundness and with given standards of safety, reliability, economy and environmental protection.

1. Task Force Hydor Report Number One
Hydro in Ontario – A Future Role and Place
August 15, 1972.

FIGURE 1
THE DECISION TREE



SECTION II

FUNDAMENTALS OF NUCLEAR POWER GENERATION

Of Atoms, Neutrons, Fission and the Like

Before proceeding to a discussion of the issues, we outline the basic concepts of nuclear physics. To assist those without expert knowledge in a complex field of technology we have resorted to a simplified treatment of the subject and use of analogies.

The generation of electricity through the harnessing of atomic energy stands as a monument to the technology of our time and it behooves everyone to possess some understanding of the basic processes involved. As illustrated in Figures 2 and 3, a nuclear generating station is nothing more than a conventional plant such as the Lakeview, Lennox or Richard L. Hearn Generating Stations, but utilizing or "burning" uranium rather than coal, oil or natural gas, to produce the steam required for the generation of electricity.

All matter is composed of tiny particles called atoms. Atoms, in turn, are composed of even smaller parts, sub-atomic particles, termed electrons, protons and neutrons. The protons and neutrons comprise the centre, or nucleus of the atom; the electrons, the peripheral material, rotate about the nucleus like the planets about the sun. The number and arrangement of the electrons, protons and neutrons determine the type of atom and ultimately the properties, or characteristics, of a particular material.

For this discussion we are interested in the properties of uranium and, more specifically, the neutrons within the nucleus of the uranium atom. The key characteristic of uranium that permits it to be used as a fuel source is that when the nucleus absorbs an additional neutron the resulting nucleus is so unstable that it immediately breaks up into two rapidly moving fragments of more or less equal mass plus two or three neutrons (a process known as "fission"). When the fragments are stopped by an adjacent material there is an accompanying release of heat. However, the number of nuclei in naturally-occurring uranium going through the fission process at any one time is too small to be of significant value in producing heat. The challenge in producing useful nuclear power is to greatly increase the rate of absorption of neutrons in nuclei of uranium atoms.

CONVENTIONAL AND NUCLEAR POWER PLANTS COMPARED

FIGURE 2

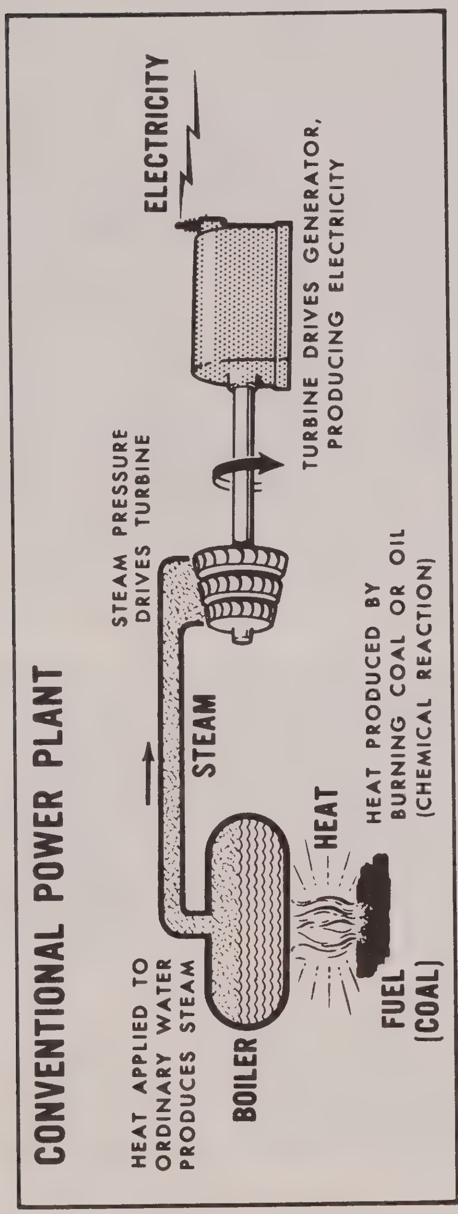
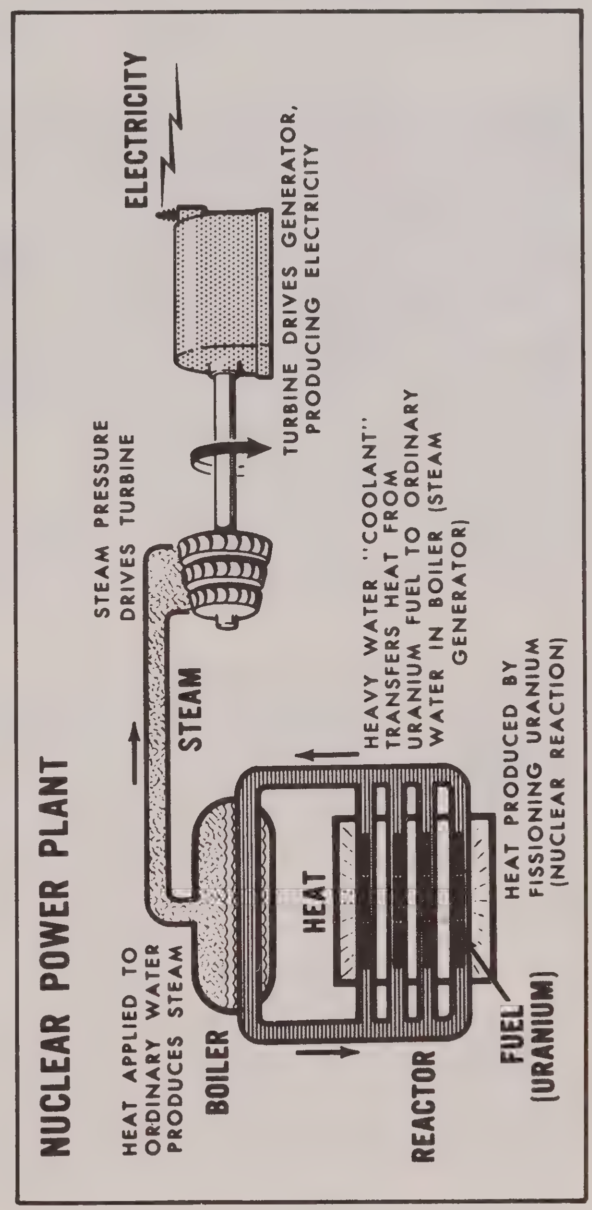


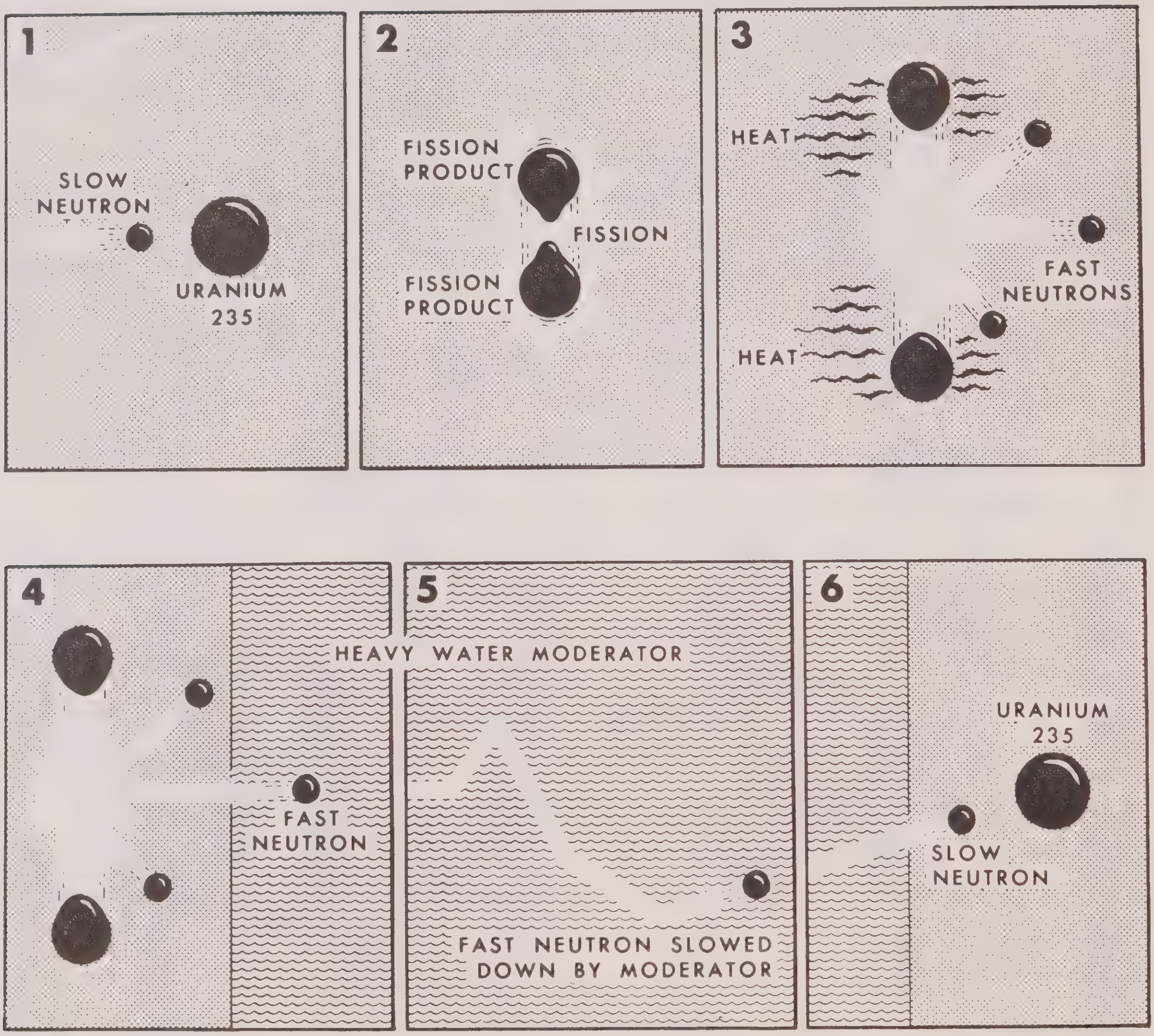
FIGURE 3



The schematic diagrams (Figures 2 and 3) illustrate the only fundamental difference—in the conventional station, stored chemical energy is released at a useful temperature by chemically combining oxygen with carbon, while in a nuclear station, "stored" energy in the nucleus of uranium atoms is released at a useful temperature by splitting the nucleus of the uranium atom (fission). This is explained in Figure 4.

FIGURE 4

FISSION OF THE URANIUM ATOM



The slow neutron (panel 1) strikes the nucleus of a Uranium 235 atom, an isotope (or form) of uranium, and splits ("fissions") it (panel 2) into fission products which fly apart (panel 3) creating great heat and some additional neutrons. The neutrons given off are slowed down as they travel through heavy water (panels 4 and 5) and the process repeats (panel 6) but with more neutrons in motion.

Normally the neutrons released during fissioning of the nucleus travel at a very high speed and therefore the chance of them striking the nucleus of another uranium atom, thereby releasing more neutrons and fragments, is small. Such is the case with meteorites and comets. Meteorites, travelling at a lower speed than comets, are captured by the earth's gravitational field and either incinerate in the atmosphere or strike the earth. The probability, or chance, of being struck by a comet is minimal.

The secret then is to slow the speed of the neutrons—a process known as moderating; the substance used to effect this decrease in speed is known as the "moderator". In order to accomplish this the uranium is immersed in the moderator (Figure 4), which might be graphite, light water (ordinary tap water), heavy water (each molecule of heavy water contains two deuterium atoms rather than two hydrogen atoms) or any other substance that will slow down, or moderate, the high speed neutrons without capturing them. The neutrons given off by splitting the nucleus of the uranium atom encounter the nuclei of atoms in the moderator and are slowed down. These slower moving neutrons are then more likely to strike nuclei of other uranium atoms causing them to split into fragments resulting in more high speed neutrons and intense heat. The result is a chain reaction.

The heat energy produced is transferred subsequently to a steam generator and, in the form of steam, to the turbines; the objective of creating electric power from the fission of uranium atoms is achieved. This heat transfer is effected by pumping a suitable coolant which, again, might be one of a variety of substances (heavy water, light water, gas or a liquid metal for example), over and around the hot uranium fuel and from there to the steam generator.

The amount of heat produced in the fission process can be controlled in several ways: through the amount of uranium fuel used, by removing the moderator or by injecting a substance which will absorb neutrons and thus reduce the number of fissions taking place (known as poison injection). In actual practice combinations of these methods are used. The heart of any nuclear generating station is the "reactor", a combination of the fuel, moderator and coolant. It is common practice to group reactor types according to the moderating system used and further classify them by the coolant. There are three main moderators in use in the world at this time which define the three major classes of power reactor: heavy water moderated reactors (HWR), light water moderated reactors (LWR) and graphite moderated reactors. The major coolants in commercial use are: pressurized heavy water (PHW), pressurized light water (PWR) (Figure 5) and boiling light water (BWR) (Figure 6), and gas cooled reactors (Figure 7).

All reactors are fuelled with either "natural" or "enriched" uranium. Naturally-occurring uranium contains two forms of uranium atom:

U-235 and U-238. Recall that an atom of a given element consists of electrons, protons and neutrons in a fixed number and arrangement. However there are atoms with the same number of protons in the nucleus but a different number of neutrons resulting in a different weight. Such atoms are termed "isotopes". The two forms of uranium U-235 and U-238, are isotopes. Deuterium is an isotope of hydrogen.

Naturally–occurring uranium consists of 99.3 percent by weight U-238 and 0.7 percent U-235. In sufficient concentrations, the U-235 isotope can sustain a chain reaction without a moderator. Such elements are often referred to as "naturally fissionable isotopes". Another isotope of uranium, U-233, has this property but does not occur in nature; it must be manufactured. When the proportion of U-235 reaches the level required to sustain a chain reaction this concentration is referred to as the "critical mass". When the release of neutrons reaches a stage in the reactor where the process is self-sustaining, either through the use of a moderator or by increasing the concentration of U-235, then the reactor is said to have "gone critical".

Reactors that use heavy water or graphite as a moderator can be fuelled with natural uranium. Reactors with other moderators, such as light water, require a fuel with a higher concentration of a naturally fissionable isotope. This increased concentration is obtained by a process known as "enrichment"; for uranium, the product is "enriched uranium" containing 2 to 3 percent by weight U-235 (cf. 0.7 percent in natural uranium). The most commonly used process for enriching uranium is the gaseous diffusion method. Though no plant has ever been constructed solely for commercial production, it is estimated that an economic plant may cost as much as one and a half billion dollars and require up to 2,000 mW of electrical power at full capacity. To date it has been possible to produce all the enriched uranium required at installations previously constructed solely for military purposes. However, it is anticipated that to handle the domestic nuclear power program in the United States alone a new commercial enrichment plant will have to be built every other year after 1980 and the demand in the rest of the world will necessitate an enrichment plant being built in each of the intervening years.

The various combinations of moderator and coolant, together with the fuel cycle and resulting acronym, are summarized in Table 1.

Table 1

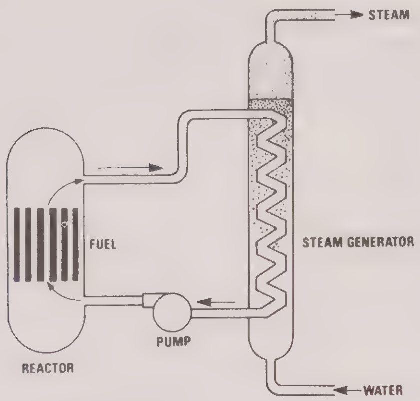
REACTOR TYPES

Name	Acronym	Fuel	Coolant	Moderator
Canadian Deuterium – Uranium – Pressurized Heavy Water	CANDU-PHW	Natural Uranium	Pressurized Heavy Water	Heavy Water
Canada Deuterium – Uranium – Boiling Light Water	CANDU-BLW	Natural Uranium	Boiling Light Water	Heavy Water
Steam Generating Heavy Water Reactor	SGHWR	Enriched Uranium	Boiling Light Water	Heavy Water
Canada Deuterium – Uranium – Organic Cooled Reactor	CANDU-OCR	Natural Uranium	Light Oil	Heavy Water
Magnox	–	Natural Uranium	Carbon Dioxide	Graphite
Advanced Gas-Cooled Reactor	AGR	Enriched	Carbon Dioxide	Graphite
High Temperature Gas Reactor	HTGR	Enriched Uranium-Thorium	Helium	Graphite
Boiling Water Reactor	BWR	Enriched Uranium	Boiling Light Water	Light Water
Pressurized Water Reactor	PWR	Enriched	Pressurized Light Water	Light Water
Liquid Metal Fast Breeder Reactors	LMFBR	Plutonium Dioxide Uranium Dioxide	Molten Sodium	None Required

REACTOR TYPES

NUCLEAR STEAM SUPPLY COMPONENTS

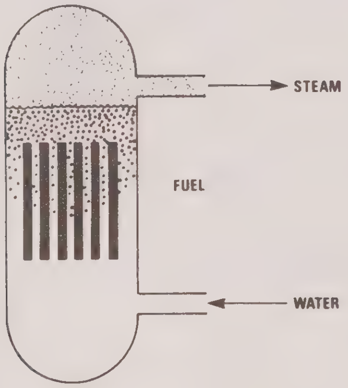
FIGURE 5 – Pressurized Water-Cooled Reactor (P.W.R)



Like the BWR this reactor is fuelled with enriched uranium and cooled with light water under pressure such that it remains liquid.

Moderator-light water
Coolant-pressurized light water
Fuel-enriched uranium

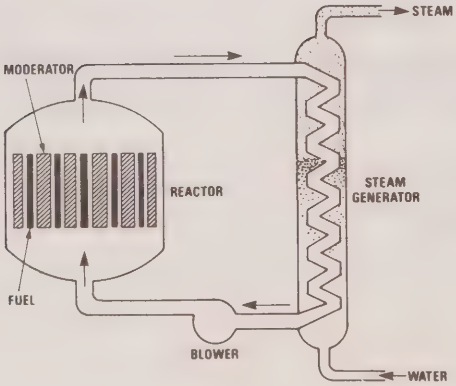
FIGURE 6 – Boiling Water-Cooled Reactor (B.W.R)



This reactor is fuelled with slightly enriched uranium and moderated and cooled with light water which is allowed to boil in the core.

Moderator-light water
Coolant-boiling light water
Fuel-enriched uranium

FIGURE 7 – Gas Cooled Graphite Moderated Reactor



Fuelled with either natural or enriched uranium. This diagram illustrates the high temperature helium cooled concept using enriched uranium carbide fuel cooled in pyrolitic carbon, which has been recently committed in the United States.
Moderator-graphite
Coolant-carbon dioxide or helium
Fuel-enriched or natural uranium.

The CANDU-PHW, Magnox, AGR, HTGR, BWR and PWR reactors have all been actively promoted in an attempt to achieve a share, and an economic advantage, in the rapidly expanding world market for nuclear power plants. At the present time over 100 of the U.S. designed light water reactors (BWR and PWR) have been built or are on order—more than half of the world's nuclear reactors. Canada has sold two CANDU-PHW plants abroad (one to India and one to Pakistan), has three prototype units operating domestically in NPD, Douglas Point and Gentilly and two multi-unit commercial stations in operation or under construction (Pickering and Bruce) in the Ontario system.

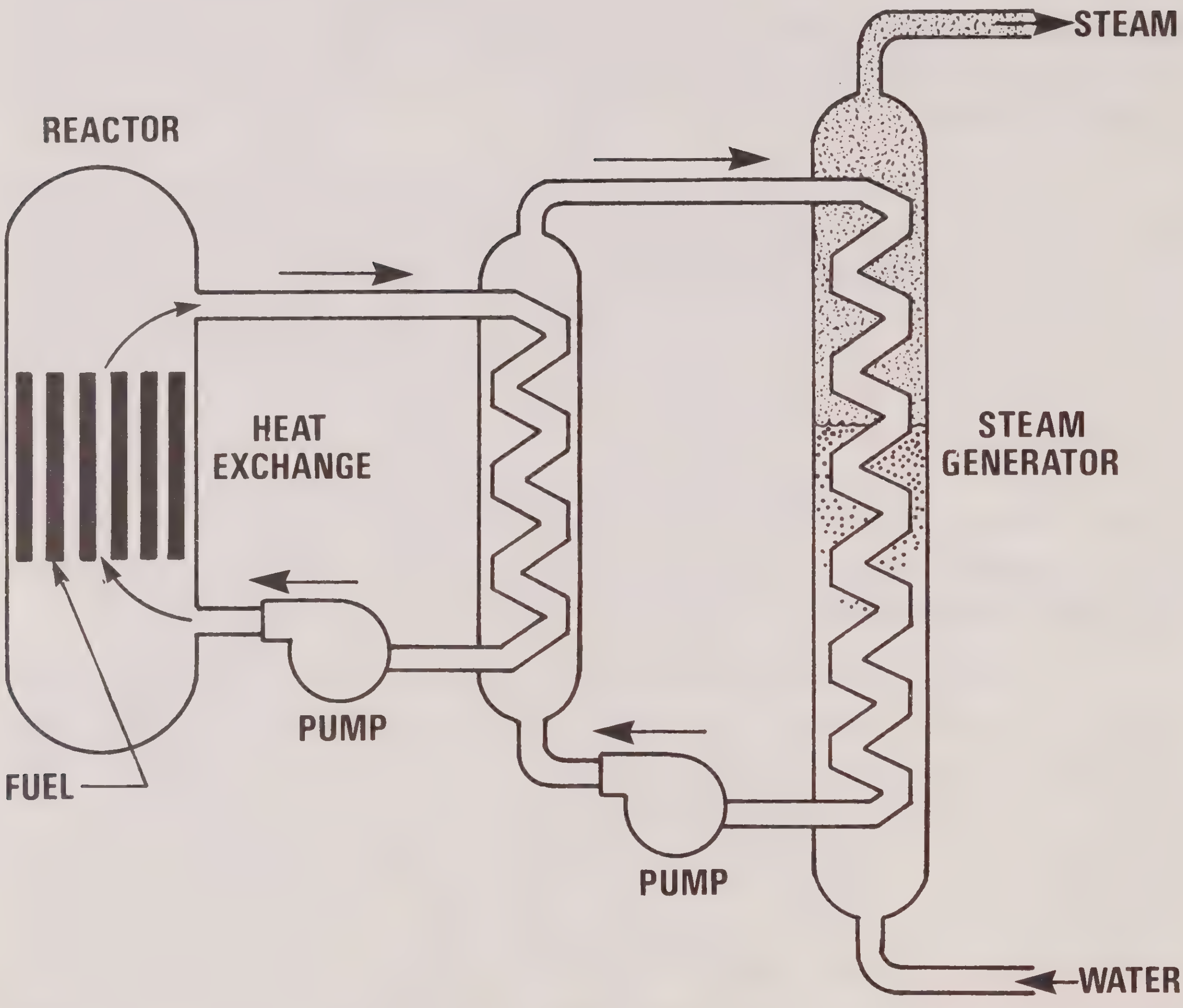
In addition to these reactor types which have been developed to the commercial production stage, research is being carried on in many countries on a concept referred to as the "fast breeder", or more commonly known as the "breeder reactor" or "fast reactor". Such reactors will be used not only in the generation of electricity but also to produce more fissile material than is consumed. The concept is too complex to be dealt with here but it is important to note that existing power reactors utilize only 1 to 3 percent of the "energy" contained in a unit of uranium. This yield can be approximately doubled by recycling the plutonium produced. Fast reactors are expected to utilize about 70 percent, increasing fuel supplies 15 to 30 fold. The fuel cycle is based on the properties of plutonium-239 (Figure 8).

Canada has been involved with an area of research related to the "breeder reactor" concept in which efforts are being made to adopt a fuel cycle appropriate to the CANDU system. This has been termed the "valubreeder concept", based on a thorium-uranium (233) fuel cycle rather than the plutonium cycle indicated previously. Research is also proceeding on a process known as "fusion", as opposed to fission. With fission, energy is released when the nucleus of an atom is split. However, energy is also released when the nuclei of two atoms are joined, or "fused". While this alternative offers great promise it is recognized that a commercial application lies several decades in the future.

NUCLEAR STEAM SUPPLY COMPONENTS

FIGURE 8

Liquid Metal Cooled Breeder Reactor



Still in the early stages of development and favoured because it is expected to produce more fissionable material than it consumes, it is fuelled with highly enriched uranium-plutonium oxide clad in stainless steel, uses minimal amounts of moderator and is cooled with liquid sodium. A unique characteristic is the heat exchanger designed to insulate the metal coolant in the reactor circuit from the water and steam in the steam generator. A leak and consequent mixing could cause a violent reaction.

The Basic Characteristics of CANDU Power Systems

The common features of the various members of the CANDU (Canadian Deuterium-Uranium) family of reactors are heavy water as moderator, the use of natural uranium as fuel, in-core pressure tubes to contain the fuel and allow circulation of the coolant in a circuit separate from the moderator, and on-power refuelling as the main method of controlling reactivity. Heavy water is the most efficient thermal nuclear reactor moderator since it absorbs fewer neutrons from the uranium fuel than any other substance. Furthermore, heavy water as a moderator makes possible the burning of low cost natural uranium as a fuel with effective burn-up rates. This is particularly desirable for Hydro because of Ontario's large reserves of uranium. Enriched uranium, the fuel required for light water moderated reactors, is costly, difficult to handle and transport, and is presently obtainable only from the United States. But, should it become economically advantageous, CANDU reactors could be operated on slightly enriched uranium. They could also be operated on uranium enriched with plutonium extracted from spent fuel discharged from the reactor or through the use of a thorium fuel cycle.

Most other reactors in the world have a large pressure vessel surrounding the fuel and moderator. The operating pressure within these vessels is related to the pressure of the coolant circulating through the reactor. Aside from the obvious manufacturing and handling problems associated with these large vessels, there are problems of safety related to contained energy, vessel integrity and emergency cooling. In addition it is difficult to gain access to the core to obtain operating information and to refuel.

To circumvent these problems Canada developed a reactor with pressure tubes, a concept dependent on the availability of a material that will absorb a minimum number of neutrons and have an adequate lifetime under the severe conditions of irradiation, temperature and stress that are imposed on it. Zirconium alloys possessing these qualities have been developed enabling the introduction of the pressure tube concept. The attractive features of this concept are the elimination of safety problems associated with a large vessel subject to high pressures, good access to the reactor core for operating control, on-power refuelling, freedom to select a coolant material different from the moderator, the absence of limitations on core size, and the demonstrated capability to readily replace any of the vital components within the reactor.

The use of pressure tubes facilitated the development of on-power fuelling. It is more difficult to develop effective on-power refuelling of pressure vessel reactors since this would require many penetrations through the head of the vessel into a congested area within the core. No light water reactors are fuelled on-power but are batch loaded instead about once a year. This not only leads to a major shutdown once a year but also necessitates a

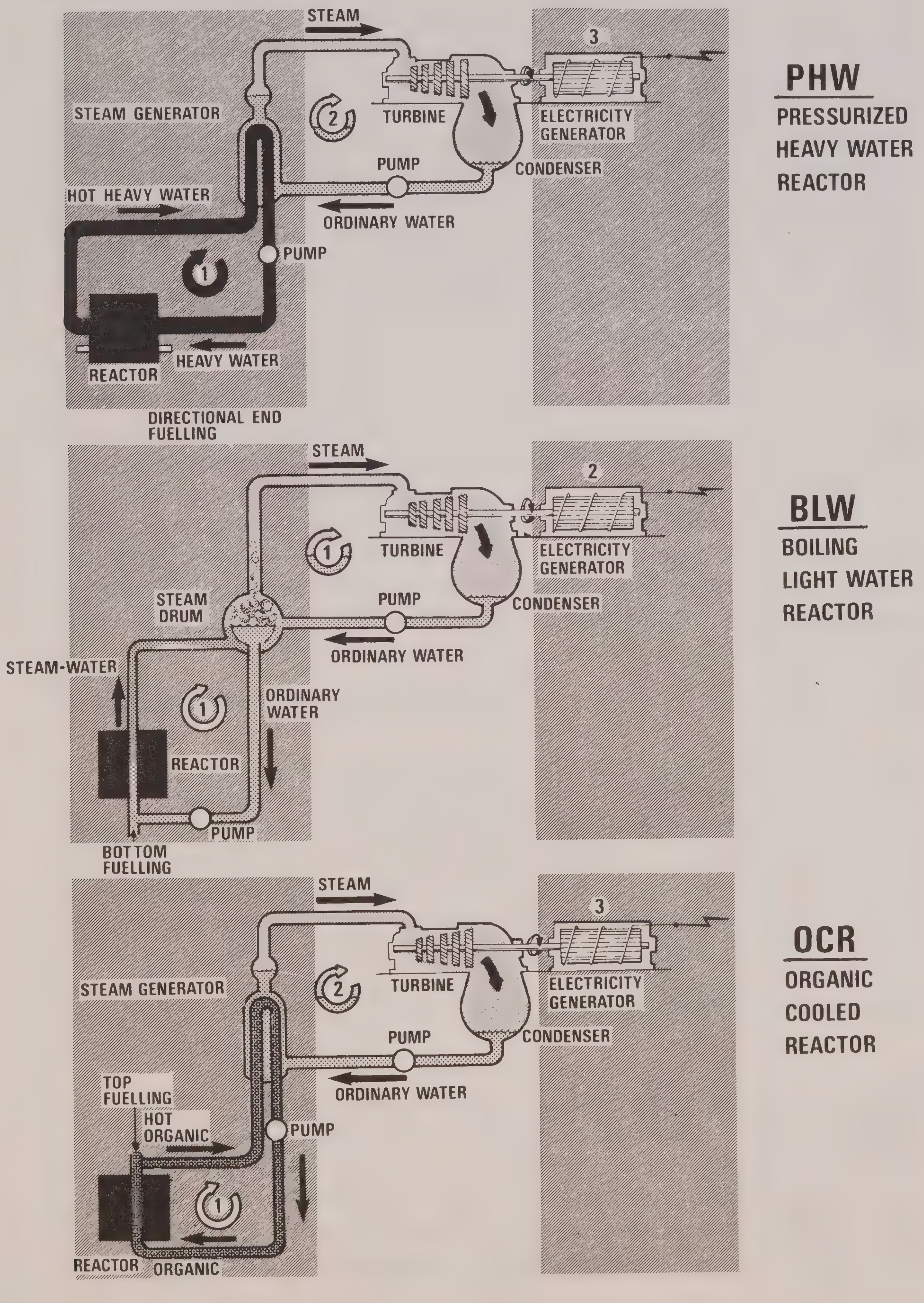
large inventory of enriched uranium to sustain the chain reaction between fuel reloadings. Also as the enriched uranium fuel is used it must remain within the reactor vessel thereby contributing to the high radiation levels. The spent fuel is radioactive. The pressure tube on the other hand permits a very small part of the reactor to be opened in isolation to the rest of the fuel and thus the reactor can be refuelled while operating at full power. On-power refuelling allows the CANDU reactors to operate with a minimum of excess reactivity in the core and to derive maximum utilization of the fuel which, in turn, contributes to a lower fuelling cost. Although there are differences in fuelling procedures in the different types of CANDU reactors, the principle in all PHW reactors is based on two identical fuelling machines operating in unison, one at each end of a reactor channel, to insert new fuel and remove spent fuel. A typical CANDU reactor operating at equilibrium full power requires replacement of about 0.2 percent of the fuel inventory per day.

There are three members of the CANDU family at different stages of development, all possessing the above features but using different coolants and associated heat transport arrangements. These three concepts, depicted in simplified form in Figure 9, are the pressurized heavy water reactor (PHW), boiling light water reactor (BLW), and the organic cooled reactor (OCR). Every CANDU unit, with the exception of Gentilly in Quebec (BLW) and the test reactor near Pinawa in Manitoba (OCR,) uses heavy water for both the moderator and heat transport system. The heavy water in the primary heat transport system is pressurized to prevent it from boiling and natural water steam is generated in an indirect cycle through a heat exchanger. The use of pressurized heavy water as a coolant has a stronger technological base than any of the alternatives. Despite the special provisions required in plant design, construction and operation, it has proven successful in early operation at Pickering and is the only CANDU concept which utilities are considering today for their large generating stations.

The main objective in using light (ordinary) water as a coolant was the elimination of the problems of high coolant cost (i.e. being required only for the moderator, the initial charge of heavy water would be less). However, if pressurized light water was used as a coolant the absorption of neutrons by the coolant would inhibit the use of natural uranium and substantially increase the fuelling cost. In the CANDU-BLW concept, the coolant is allowed to boil in the reactor. The change from liquid to vapor reduces the mass of coolant in the core and thereby reduces the absorption of neutrons to a level that will allow economic utilization of the natural uranium fuel.

FIGURE 9

HEAVY WATER POWER REACTOR SYSTEMS



The steam generated in the reactor is fed directly to the turbine via a steam drum, obviating the need for a heat exchanger. The only existing station of this concept is the Gentilly Nuclear Power Station in Quebec. Several years of operation will be required, in order to establish the performance characteristics, before a major commitment for a power station with this concept is undertaken. The development of this system is considered to be 8 to 10 years behind the pressurized heavy water cooled concept.

The use of an organic liquid, such as a light oil, as a coolant for heavy water moderated reactors has been under investigation for a number of years both in Canada and Europe (by Euratom). The advantages of an organic coolant include reduced radioactivity and corrosion in the system. However, it is flammable and great care must be exercised in handling the coolant. The CANDU OCR near Pinawa, Manitoba has been tested successfully at power reactor conditions though no steam or electricity has been produced.

SECTION III

THE CANDU PROGRAM

The Nuclear Club

The United States, United Kingdom, France, USSR, and Canada have had major national nuclear power development programs for many years and, more recently, Germany, Japan and Italy have joined the "nuclear power community". As an active member of this community, Canada is well in the mainstream of current nuclear activities. Canada plays an integral part through its membership in the United Nations' International Atomic Energy Agency and its associate membership in the Nuclear Energy Agency (an affiliate of the Organization for Economic Cooperation and Development). Canada has signed and ratified the Treaty on Nonproliferation of Nuclear Weapons (NPT). Furthermore, inter-governmental bilateral agreements for cooperation in the peaceful uses of atomic energy have been signed with Australia, Euratom, (the atomic arm of the European Economic Community), the Federal Republic of Germany, India, Iran, Japan, Pakistan, Spain, Sweden, Switzerland, the United Kingdom and the United States. Finally, Atomic Energy of Canada Limited (A.E.C.L.) has formal agreements with similar agencies in France (CEA), Italy, Romania and the USSR. The principal objective of all these agreements is the exchange of scientific and technological information. Recent technical data and experience on CANDU have been fully disclosed in the literature and at international conferences.

Nuclear Power Development in Canada

Ontario Hydro was interested in the potential of atomic energy as a power source from the time research into the peaceful uses of nuclear energy began in Canada over twenty years ago. In 1953, Ontario Hydro and A.E.C.L. agreed to work toward the construction of a nuclear-power station. The preliminary design study, undertaken at Chalk River in 1954-55 by A.E.C.L. and engineers from utilities and private Canadian companies, resulted in a 25 MW demonstration unit known as Nuclear Power Demonstration (NPD). This demonstration reactor, built at Rolphton, Ontario, was started up (went critical) in 1962. This was the prototype for the first large commercial plant.

The NPD study was followed in 1955-57 by a design study of a full-scale nuclear power plant by engineers provided by five Canadian companies and Ontario Hydro. The objective of this study (NPG-10) was to develop an outline specification and conceptual design of a nuclear power plant fuelled with natural uranium and moderated by heavy water. In 1959 it was announced that the decision had been taken to build such a plant. The

200 MW generating station was built at Douglas Point, Ontario and went critical in 1966. Owned by A.E.C.L., it is operated by Ontario Hydro.

Not everything went smoothly at Douglas Point. But this was not unexpected since it was, after all, the first prototype of a commercial station. As a result, the initial capacity factors were low and the station was closed several times for alterations and repairs, often in the conventional portion of the power plant. Eventually the problems were resolved and the knowledge gained has served well the designers of Pickering and Bruce; the initial high capacity factors for the Pickering Generating Station are testimony to this. Once the difficulties had been overcome, the availability of the nuclear power reactor began to increase, and today Douglas Point also enjoys very high capacity factors.

In 1963, a year after the start up of NPD, A.E.C.L. and Ontario Hydro held further discussions which culminated in July of 1963, in an agreement to undertake a co-operative study of a multi-unit, heavy water moderated nuclear power station. The study was completed in twelve months. A project outline, issued in June 1964, complete with cost estimates, was the basis of commitment in September of the same year for the first two units of the Pickering Generating Station. The reactor concept, although based on the Douglas Point arrangement, was to be an integrated multi-unit station of four, 540 MW units with a completely new negative-pressure containment system, new control protective arrangements and other new systems and components, all of which had to be conceived and redesigned. No significant equipment or system development work was undertaken during the one year study period. This led to difficulties in controlling the subsequent design since important development work was being carried on concurrent with the design.

The first unit of the Pickering Nuclear Generating Station went critical in the summer of 1971, followed by units two and three at intervals of about six months. The fourth unit is scheduled to go critical in 1973.

In February 1967, Ontario Hydro authorized the initiation of a preliminary study of a nuclear power generating station consisting of four 750 MW units. As with Pickering, this was a co-operative Ontario Hydro—A.E.C.L. study. The preliminary design study, a project outline and cost estimates were completed and issued in April, 1968. This was to become the Bruce Generating Station.

During the study of the 750 MW nuclear steam supply system (NSSS) consideration was given to alternative reactor arrangements, size and rating, operating conditions in the heat transport system, fuel handling systems, and control and protective arrangements. The objective was to simplify the design, minimize the number of components and systems,

maximize the accessibility for maintenance, and design for a high degree of reliability by utilizing proven components. The project outline, issued in April 1968, was based on about 35 man-years of effort. Little or no development work took place during this period.

Commitment of the Bruce Generating Station followed in December 1968. Although the basic reactor arrangement is the same as Pickering, the increase in the output of the individual units, the changes in arrangement to improve accessibility and maintainability, changes designed to improve heavy water recovery and changes to reduce the number of components and systems resulted in a complete redesign of all civil works and mechanical and electrical systems. The first unit is scheduled to go critical in 1975.

The 250 MW Gentilly Nuclear Power Station near Three Rivers, Quebec, designed and built by A.E.C.L. with the cooperation of Hydro Quebec, represents the latest Canadian prototype. The conceptual and early development phase of this project was undertaken at Chalk River in 1963-1965 and the design officially commenced in 1966. It was fuelled with natural uranium, moderated with heavy water and cooled with boiling light water (CANDU-BLW). The reactor went critical in 1970.

An organic cooled test reactor has been operating successfully for several years at A.E.C.L.'s Whiteshell Nuclear Research Establishment (WNRE) near Pinawa, Manitoba. Before commercial application of the CANDU-OCR is contemplated, a prototype system of about 500 MW capacity would be required. A study of a nuclear power station using an organic coolant was completed by A.E.C.L. late in 1972. A decision not to proceed with construction at this time was recently made.

CANDU Projects Outside of Canada

Ontario Hydro has given, and continues to give, substantial assistance in the commissioning phase of the CANDU Rajasthan Atomic Power Project (RAPP) in India, and has played a small part in the commissioning of the Parkistan reactor (KANUPP), supplied by Canadian General Electric.

Foreign Assessments of CANDU

The lack of major success in the export market, even though A.E.C.L. has been actively pursuing the sale of CANDU reactors, has led to claims that foreign buyers do not favour CANDU as a consequence of deficiencies or short-comings in the system. If indeed this is the case then these factors must be considered by Ontario Hydro in any future decisions. Therefore it was essential that the reasons why other nations have chosen reactors other than CANDU be determined.

Experts in agencies and utilities responsible for the development of nuclear power systems and the generation of electrical power were interviewed in the United Kingdom, France and the United States. All three countries have had close working relationships with A.E.C.L. and were reasonably familiar with the CANDU system. Sweden, South Africa and Japan have had direct experience with heavy water systems or have conducted comparative studies of CANDU with other reactor types. Available reports and literature from these three countries were studied. The objective was not to make detailed analyses and assessments of the programs in these six countries but, rather, to gather an impression of their attitude to CANDU.

United Kingdom and France

The nuclear power program in the United Kingdom has been marked by sudden switches from one reactor concept to another. The first generation used natural uranium fuel and carbon dioxide cooling (Magnox). However corrosion problems, caused by the reaction of carbon dioxide with mild steel in a radioactive environment, eventually led to a derating of all Magnox reactors. The next step was a reactor termed the Advanced Gas-Cooled Reactor (AGR) and five are now under construction. Once again it appears likely that future construction will not be committed because of corrosion problems. The United Kingdom therefore stands at the crossroads debating which route to pursue, Steam Generating Heavy Water Reactor (SGHWR) or LWR, hoping that the fast breeder concept will become commercially operational before a firm commitment has to be made.

France has commitments for five, 900 MW pressurized light water reactors (PWR) to be designed and built by Creusot Loire under licence from Westinghouse in the United States. One additional reactor is on option and will probably be committed soon. Before committing the five light water reactors, France did consider a heavy water reactor similar in design to Pickering—the EL-600. During the preliminary design stages there was close cooperation between France and A.E.C.L. on the heavy water reactor technology but there was too much uncertainty surrounding the performance of CANDU at that time to select the EL-600. Furthermore, on the basis of their own economic analysis the light water reactor appeared to be slightly less costly on a unit energy basis (nine, compared to ten, mills per kWh).

The French enthusiasts for a fast breeder reactor are hedging somewhat on the commitment of a large commercial unit (1200 MW) preferring instead to operate a prototype first (Phoenix, a

250 MW fast breeder, is scheduled for operation in 1974). A British prototype fast reactor at Dounreay in the north of Scotland was to have gone critical in 1972 but, according to the latest estimates, will not be in operation before 1973.

As far as the utilities in both countries are concerned, the most important factor in assessing any reactor type is actual performance and reliability. Since the capital costs of competing reactor types are likely to differ by only a few percentage points, the low fuelling cost argument associated with CANDU reactors has some impact, but availability is uppermost in the minds of utility executives. The longer CANDU remains in reliable service the greater will be the world's confidence.

Neither country expressed any concern about the long term supply of uranium, an assessment based on the assumption that the fast breeder reactor will be available in the 1980's. However, there is an underlying fear in both countries that United States technology in the nuclear power field will dominate the world unless some attractive alternative can be evolved in time. Both countries were of the opinion that the pressure tube reactor seems to offer that alternative and it would not be surprising to see the United Kingdom move toward the SGHWR, a relative of the CANDU family, for future nuclear generating stations pending the availability of a fast breeder reactor. In that event the French probably would follow suit.

It was evident that the Pickering performance has enlivened or rekindled interest in heavy water reactors and all groups visited in the United Kingdom and France were of the opinion that, in the light of the extensive Canadian experience, Canada should continue to promote the CANDU concept. Our strength has been in the single mindedness of our program, in contrast to the United Kingdom and France who have changed directions radically over the past twenty years. It is possible that within the near future, a "heavy water club" could be formed with Canada, the United Kindom and France forming a "troika" to promote further the development of pressure tube reactors.

Neither the United Kingdom nor France believe they can create a viable nuclear industry alone, or at least without exports. Such being the case, they seriously questioned whether Canada could afford the cost of CANDU based on internal sales alone. In the long term, it was feared, the Canadian learning curve will not prove to be sufficiently steep or advanced to maintain cost competitiveness with other countries and consortia selling in much broader markets than those available in Canada alone. At some

time in the future Canadian utilities, such as Ontario Hydro, could be driven to buy off-shore reactors.

United States

We were interested to learn the factors that influenced the decision of a United States utility to select a particular nuclear power reactor. Philadelphia Electric, a typical East Coast utility, chose the high temperature gas reactor (HTGR) developed by Gulf General Atomic in lieu of a Westinghouse pressurized water system or a General Electric boiling water reactor. Philadelphia Electric previously had decided on the General Electric boiling water reactor and four 1,050 MW BWR units are being constructed. The main advantage Philadelphia Electric perceived in selecting the HTGR was to have more than one type of reactor in their system; if any generic fault develops in one type, requiring all of this type to be derated or even shut down, it would not necessarily wipe out or severely cripple their generating capacity. For this reason the selection was between the PWR and the HTGR, rather than the BWR. Economic comparisons revealed that the cost of power from the HTGR would be lower than from a PWR and for several technical reasons they believed the HTGR would be easier to licence. These were the principal factors that influenced their decision.

Arguments on comparative capital costs apply to a normal, predictable construction program for a nuclear power station. The situation today in the United States is far from normal. Following the passage of the National Environmental Protection Act, a utility must file an environmental impact statement before it can obtain a construction permit, let alone an operating licence. Furthermore, public hearings are causing long delays. Philadephia Electric is presently responding to over 3,000 questions raised by the public with respect to two of their BWR stations (they are also being severely criticized for marketing appliances and thereby fostering an increase in the demand for electric power).

The Atomic Energy Commission (AEC) in the United States reported that as of March 1972, no new construction permits or operating licences had been issued since early 1971. While some construction permits were issued in 1972, these unplanned delays have resulted in a shortage of power, particularly in the eastern states, and have cost the utilities countless millions of dollars. The environmental issue stands out as the largest single cause of delay and anxiety among utilities in the United States today. Public

apprehension centres on two concerns–radioactive and thermal discharges.

Because of significantly lower fuel costs, and a simpler fuel cycle the question of exporting CANDU reactors to the United States was explored. Two disadvantages were noted. Its higher capital cost would make it presently unattractive to utilities with higher fixed charge rates. Also, its characteristic "positive void coefficient" could lead to reservations with respect to the granting of an operating licence.

This may require some elaboration. The significance of this term is that a reactor having a "positive void coefficient" requires some external controls to shut it down in the event that there is a sudden loss of coolant. Reactors having a "negative void coefficient" as do the light water reactors, shut themselves off in similar circumstances. In the event of loss of coolant the CANDU reactors are shut down by an engineered safeguard: shutoff rods inject "poison" into the moderator stopping the chain reaction. The positive void coefficient is characteristic, to a very small extent, of the heavy water cooled version, but even more so in the use of the BLW and OCR versions of the CANDU. This characteristic is not considered a major problem to reactor engineers or scientists, since safeguards are triplicated and can be tested at power, but the characteristic may be a point of objection by any group not wanting to see another reactor type enter into the U.S. However this objection could soon become less relevant since the fast-breeder has a positive void coefficient and very responsive engineered protective systems will be required to shut down these reactors in the event of loss of coolant.

While the performance of Pickering is recognized as being impressive, the view was expressed that at least another year of operation is required for an effective demonstration. Pickering might be considered to be a first generation commercial prototype. In terms of development it would be considered midway between the Gulf General Atomic's high temperature gas cooled reactor (HTGR), at present only a 40 MW unit has been operated at full power, and the light water reactors (PWR and BWR) of which there are more than 100 operating or under construction.

While it was agreed that CANDU has the lowest cost fuel cycle, this alone does not balance the cost of borrowing the additional capital required. It should be recognized that most United States utilities use a higher fixed charge rate in calculating the cost of borrowed capital. However, there was a general feeling that the capital cost per installed kilowatt of CANDU-type reactors could

become competitive when the CANDU is constructed in 1,100 MW unit sizes or larger as compared with the 540 MW units at Pickering and the 750 MW units at Bruce.

Concern was also expressed about who stands behind the CANDU design and warranty, and the adequacy of financial backing. They were unaware of the structure of A.E.C.L. In addition, national loyalty to domestic designs was apparent; it was concluded that the only way CANDU could enter the United States would be through the licencing of the design to a very large United States corporation.

Some comments should be directed toward the term—national loyalty. During the Second World War, Canada, the United States and the United Kingdom agreed to cooperate on atomic energy. The United States was to pursue light water reactors; the United Kingdom was to research graphite moderated reactors and Canada the heavy water route. The nuclear power program in the United States was to benefit greatly from the monies spent on the nuclear submarine program. The AEC in the United States maintained a co-operative program with A.E.C.L. on heavy water reactors throughout the 1960's spending $10 million through to 1971. Since then all work on heavy water power reactors has been abandoned. The AEC pointed out that historical roots play a large role in the decision of any country as to which direction it will follow in its nuclear power program, and felt that Canada was justified in persisting with the heavy water technique. They cited British loyalty to their gas cooled reactors and the deep roots of the light water systems in the United States.

In 1970 Edison Electric Institute of the United States conducted a comparative evaluation of all contending reactor types, including the CANDU, and concluded that the PHW version of CANDU, while possibly best for the Canadian circumstances, would not be economical in the United States where capital is more costly. Future BLW and OCR versions, however, could be more promising if projected capital cost savings are realized. They referred also to the difficulty of licencing CANDU in the United States because of the positive void coefficient. The report concluded that the liquid metal fast breeder reactor (LMFBR) would not reach the commercial stage until the 1990's and as a consequence, the present generation of light water nuclear power reactors will dominate the market for the next 20 years.

One interesting comment made during the discussions was that Canada tended to publicize all breakdowns in the reactor system even though they might be only minor. Though such action is

scientifically commendable, several of the United States participants believed this type of publicity could only tarnish the image of an otherwise excellent nuclear power station (Pickering). They remarked that utilities and suppliers in the United States would not consider many of the problems reported from Douglas Point, for example, to be of sufficient importance to relay to other agencies and, indirectly, to possible purchasers of the reactor concept. In a world of competitive marketing such releases can result in damage to the CANDU cause.

Sweden

Sweden started its own nuclear program in 1947, concentrating on heavy water reactors using natural uranium. The Swedish government wished to establish independence from speculative supplies of enriched uranium and believed that large reactors using heavy water moderation and utilizing the extensive, low grade domestic uranium reserves would be economical. A 65 MW thermal, pressurized heavy water experimental reactor, Agesta, was built and connected to the power grid in the early 1960's. It was operated by the State Power Board and showed excellent availability and performance.

Development work toward a more advanced heavy water reactor led to the Marviken project, intended to bridge the gap between Agesta and reactors of full commercial size. Marviken was to be a 200 MW boiling heavy water reactor with a direct reactor-to-turbine cycle with provision for superheat, using natural uranium and on-load refuelling. It was anticipated that such an advanced and novel design would help close the nuclear power reactor gap between Sweden and countries that had made an earlier start. The decision to proceed with Marviken was taken by the Swedish government in 1963 on the recommendation of the State Power Board.

Meanwhile, a number of Swedish private and municipal utilities developed an interest in light water, enriched uranium reactors as an alternative to the heavy water system. After a number of studies and proposals this group, representing nearly 40% of the generating capacity in Sweden, decided to order light water reactors in the 400-500 MW size range. Two reactors of the boiling light water variety, patterned after the United States BLW, were built by Swedish industry but, nevertheless, they were an original Swedish concept and design. The first was started in 1966 and scheduled for completion in the early 1970's. The second was started in 1970 to come into service in 1974.

The heavy water activity in Sweden suffered a setback when India and Pakistan decided in favour of CANDU. Questions were being raised by government officials as to whether their reactors would be able to compete in price against light water reactors which were being developed rapidly and making inroads in Europe.

By late 1968 the initial tests on Marviken revealed technical problems associated with reactor control characteristics and excessive condensation in the fuel channels. These faults resulted in a reassessment of the costs to completion. By this time the State Power Board had become disenchanted with the Marviken project which started to appear excessively ambitious but, more important, was becoming irrelevant; a large portion of the Swedish power grid was thoroughly committed to light water reactors, undoubtedly influenced by developments in Germany and the impatience of the other Swedish utilities to get into the nuclear power business.

While Marviken's technical problems were relatively easy to rectify, the delay and additional cost of bringing it into service could not be justified. The Swedish government decided to disengage itself from heavy water reactor development and discontinued the program in April, 1970.

Some persons have pointed to the Marviken project as a direct comparison to CANDU arguing that if the concept was uneconomical for Sweden then surely CANDU, being similar, is too expensive for Canada. However these critics err in their belief that Marviken and CANDU-PHW are similar. While both use heavy water as moderator and coolant the similarities end there. The CANDU uses pressurized heavy water as coolant, generating steam for the turbines in an indirect cycle. The Marviken project involved not only letting the heavy water boil but also feeding the resulting steam directly to the turbine and it was from this part of the concept that the troubles and high cost arose. For example, using this concept results in significant radiation levels around the turbines! It should also be noted that Marviken was a pressure vessel reactor and the prospects of building pressure vessels large enough for output above about 500 MW are not bright. Furthermore, on-power fuelling as in CANDU was not possible. The two reactor systems are not comparable; nothing more need be said.

The Republic of South Africa

South Africa has conducted studies comparing several power reactor systems, including CANDU. With no nuclear power pro-

gram of their own, and subject as they are to possible embargoes from other countries, South Africa is a good example of a country not already committed to a specific reactor type, yet possessing an indigenous source of uranium and the assurance of being self-sustaining in uranium after a nuclear power plant is installed.

The first report, dated May 1968, concluded that there must be absolute assurance that nuclear fuel would be available over the entire lifetime of the station. Because the continued and assured supply of enriched uranium for a power reactor in South Africa was, at that time, subject to grave doubts, only those types of reactors capable of operating on a feed of natural uranium were considered. This limited the comparison to two types, the British gas-cooled and graphite-moderated (Magnox) reactor and the heavy water cooled and heavy water moderated reactor (CANDU-PHW). They concluded that under South African conditions the latter had more favourable economic and technical features than the Magnox reactor. They recognized that light water reactors may be more economical than the natural uranium types and should be considered if, at the time of placing an order, the uncertainties regarding an assured supply of enriched fuel had been resolved.

The second report, dated September 1970, broadened the comparative study to include light water reactors. It concluded that, using South African ground rules (i.e. no cost was included for the enrichment plant), the enriched reactor systems appeared capable of generating electricity at a unit cost up to 20 percent lower than the natural uranium systems. Therefore, on purely economic grounds, the obvious choice would be one of the two light water cooled versions, BWR or PWR. Although there were doubts about the long term integrity of pressure vessels, the BWR and PWR were the only two economic light water systems that could be considered fully proven and the study showed that their capital and operating costs were close enough to be considered identical. If, however, complete independence from an overseas enriched uranium supply was considered to be essential the choice would be CANDU. However, in the light of an announcement regarding uranium enrichment in South Africa, dependence upon an overseas supply of enriched uranium might not be necessary, though, as was pointed out earlier, the arguments never discussed the cost of an enrichment plant in South Africa.

At the time of these evaluations CANDU was relatively unproven in commercial operation and the reports allude to uncertainties with respect to factors affecting safety, reliability and operating costs that have since been disproven.

Japan

The 1970's will see a tremendous growth in nuclear power generating capacity in Japan, with 8,660 MW forecast by 1975, and 32,000 MW by 1980; at that time 23% of the total electricity supply will be nuclear, according to the Fourteenth Annual Report of the Japan Atomic Energy Commission, covering the years 1969 to 1970. Japan was late in starting a domestic nuclear power development capability, and so the initial installations were of United States design with 4,651 MW capacity of BWR and PWR types, either operating or under construction in early 1970.

Since nuclear power generation will be the principal source of future energy in Japan they have embarked on a program of reactor development and fuel cycles that will ensure the security of fuel materials and a nuclear industry strong enough to be competitive in the future world market. A heavy water moderated, boiling light water cooled pressure tube reactor, called the Advanced Thermal Reactor (ATR), which could be operated with natural uranium, was chosen for domestic development in parallel with a fast breeder reactor program. Both of these systems use nuclear fuel more efficiently than light water types of reactors and it is believed that they should be competitive in operating costs. The Japanese envisage the introduction of ATR into commercial service during the latter part of the 1970's and the fast breeder a decade later.

The ATR program was initiated in 1967. Construction started in 1970 on the prototype 165 MW reactor, FUGEN, scheduled to go critical in 1974. It is designed to utilize either plutonium-enriched fuel mixed with natural uranium or slightly-enriched uranium containing 1.5% U-235. It will use vertical pressure tubes, a technology purchased from A.E.C.L.

Thus Japan has chosen a boiling water cooled-heavy water moderated reactor for commercial development, similar in principle to the Gentilly reactor in Quebec, because they believed that such a system can offer lower operating costs and, presumably, the flexibility in the use of enriched fuel provides them with some independence from future uncertainties in available enrichment facilities and costs. It is too soon to evaluate their success with FUGEN.

SECTION IV

THE ISSUES

To continue the pursuit of any nuclear alternative, and more specifically the CANDU system, questions arising from four basic issues must be considered:

- Reliability
- Environmental Quality Implications
- Cost
- Unit Energy Cost

Reliability

The overall technical performance of a generating station may be defined in terms of its capacity factor–the ratio of the average power load to its rated capacity, expressed as a percentage. In a nuclear plant the capacity factor covers the performance, not only of the conventional portions of the station including the turbines and generators, but also the nuclear steam supply system. The availability of the nuclear steam supply system alone would be more useful in comparing reactor types, but it was not possible to obtain reliable availability figures for alternative types. Nevertheless, capacity factor does include availability and is probably more meaningful from the standpoint of comparative overall system performance since the fact that the station generates electricity is more significant than the fact that the reactor itself is in operation.

Table 2 is a summary of capacity factors for a number of in-service nuclear generating stations in the United States, West Germany, the United Kingdom, France and Canada. It illustrates one of the difficulties this country faces in competing with alternative types–Canada's history of success is too short. The early high capacity factors are encouraging, at 81% for Pickering 1 and 82% for Pickering 2, but at least another year of operation is needed before entirely valid comparisons can be made[2]. However, it is important to note that the two units at Pickering have higher capacity factors than any other reactor operating the same length of time. A recent report from the United States indicates that up to October 1972 the average capacity factor for 18 reactors operating in that country was 60.9 percent. This is considerably below the 80 percent forecast which attracted the utilities because conventional fossil-fired were averaging only about 75 percent.

Some design features of CANDU reactors have an important bearing on operating reliability. Perhaps the most important is core access. Re-

2. For the period December 1st 1972 to February 28th 1973 the capacity factor for Pickering Units 1, 2 and 3 combined was 96.0 percent.

actors with pressure vessels, including both PWR and BWR, can present maintenance problems if difficulties arise with the fuel or components housed within the reactor vessel. The pressure tube design of CANDU, on the other hand, permits more ready access to the reactor core than pressure vessels and therefore a much shorter time is required to replace or repair a damaged component. Another feature is the on-power refuelling capability. This is in contrast to pressure vessel reactors which, normally, are shut down an average on one month each year for refuelling. Periodically, the turbines in CANDU stations do have to be balanced and other maintenance performed, but the shut-down period need not be as long as for light water reactors. Further, on-power refuelling permits the extraction at any time of faulty fuel elements which, in the case of light water reactors, have to remain in the core until the reactor is shut down.

It has been argued by some utilities that a mixture of reactor types in their systems is desirable in the interests of increasingly system reliability. Then, if a generic fault appears in one reactor type, the entire nuclear portion of the system need not be affected. Experience with the Magnox reactors in the United Kingdom is cited in support of this argument where unanticipated corrosion problems resulted in the derating of all reactors of this type for the balance of their lifetimes. Philadelphia Electric's HTGR at Peach Bottom was inoperable for a year while the design of the fuel elements was corrected to compensate for defects that appeared unexpectedly.

Ontario Hydro already has ten years operating experience with NPD so that inherent generic design faults should have been revealed by now. Also it will be well over a decade before the nuclear component of the network appreciably exceeds the reserve margin by which time there will have been gained many additional years of operating experience with the generating stations now in the system and others yet to be put in service.

Table 2

NUCLEAR GENERATING STATION CAPACITY FACTORS

Country	Generating Station	Type	Gross Output MW	In Service	Average Capacity Factor—In Service to Jan/72
United States	Shippingport	PWR	100	1957	45.6
	Yankee Rowe	PWR	185	1961	83.5
	Indian Point	PWR	285	1962	47.9
	Conneticut Yankee	PWR	590	1968	76.4
	San Onofre I	PWR	450	1968	69.4
	Dresden I	BWR	210	1960	54.6
	Humboldt Bay	BWR	65	1963	68.1
	Big Rock Point	BWR	75	1965	55.7
	Oyster Creek	BWR	540	1970	75.2
	Nine Mile Point I	BWR	525	1971	54.3
	Hanford I	Graphite/ $H2^o$	800	1966	45.6
	Peach Bottom I	HTGR	45.5	1967	46.3
West Germany	Gundremmingen	BWR	250	1967	65.1
	Lingen	BWR	252	1968	68.0
	MZFR	PHWR	57	1966	45.1
	Obringhiem	PWR	345	1968	81.8
United Kingdom	Calder Hall	Magnox	219	1956	57.5
	Chapel Cross	Magnox	228	1959	78.5
	Berkeley	Magnox	334	1962	75.0
	Bradwell	Magnox	374	1962	68.1
	Hunterston	Magnox	360	1964	81.0
	Hinkley Point 'A'	Magnox	664	1965	59.2

Table 2 continued

Country	Generating Station	Type	Gross Output MW	In Service	Average Capacity Factor—In Service to Jan/72
United Kingdom (Cont.)	Transfynydd	Magnox	584	1965	63.3
	Dungeness 'A'	Magnox	576	1965	65.4
	Sizewell	Magnox	562	1965-6	68.6
	Oldbury	Magnox	633	1966-7	51.7
	Windscale	A.G.R.	41	1962	63.5
	Winfrith	SGHWR	100	1967	53.2
France	Marcoule	Gas/ Graphite	80	1959-60	76.2
	Chinon 2	Gas/ Graphite	242	1967	61.5
	Chinon 3	Gas/ Graphite	489	1967	34.0
	St. Laurent des Eaux I	Gas/ Graphite	500	1969	27.3
	St. Laurent des Eaux 2	Gas/ Graphite	530	1971	48.9
	Chooze (sena)	PWR	282	1967	33.9
	Monts d'Arres	GCHWR	73	1971	40.7
Canada	Pickering I	PHW	540	April 1971*	81**
	Pickering II	PHW	540	October 1971*	82***

* From first full power
** May 30/71 – Mar. 31/72 (10 months)
*** Nov. 7/71 – Mar. 31/71 (5 months)

Source: Ontario Hydro Generation Concept Department. March 1972.

Environmental Quality Implications

Public concern regarding the quality of the environment has important implications with respect to the generation of electrical energy. While the generation of electrical energy gives rise to varying degrees of atmospheric and water pollution, paradoxically, electricity will probably become the major energy source involved in improving environmental quality

National concerns have given rise to increasingly stringent standards regarding the concentration of sulphur and nitrogen oxides in the atmosphere. Since there are limited supplies of natural gas, desulphurized fuel oils and low-sulphur coals, Ontario Hydro has had to rely increasingly on facilities to remove sulphur from the effluent gases. Research is continuing but it cannot be anticipated that sulphur emissions, arising from the combustion of fossil fuels, will be under control before 1980 or 1985. When perfected, the added cost of these controls will be reflected in increasing costs of fossil-fuelled stations which, presumably, will improve the present cost competitiveness of nuclear power.

Although nuclear power plants do not discharge sulphur dioxide, oxides of nitrogen or particulates, environmental problems of a different kind exist. These include in-plant and atmospheric contamination by radioactive products of the fission process, long-term storage of spent nuclear fuel and thermal discharge. The first problem, in particular, calls for the development of sophisticated protection and control systems if more stringent standards are to be established by the Atomic Energy Control Board (A.E.C.B.). Existing protection and control systems in Ontario Hydro satisfy current standards established by the Board.

In-plant safety relates to the minimization of radiation exposure in the working areas of the power station. One procedure is to improve plant design so that the radiation fields are reduced; this involves increased capital expenditures. The other is to tolerate a somewhat higher radiation field but to employ more maintenance staff so that the cumulative dose per worker, over a period of one or more years, is no greater than the cumulative dose associated with the more advanced design. In other words, the problem can be handled either by increasing capital costs or by increasing operational costs.

In order to guard against atmospheric contamination by radioactive products of the fission process, nations involved with nuclear power programs undertake rigorous monitoring of the environment, especially in the vicinity of the power plants. The foundation of radiation protection standards has been based on an extensive international research program. For instance, the general guidelines are recommended by an independent scientific body—the International Commission on Radiological Protection. It

should be noted, however, that since there is in effect no *safe* threshold of radiation there is an inherent difficulty in establishing protection standards.

In Canada, Ontario Hydro, A.E.C.L. and public health authorities have been monitoring localized environments for a number of years and the results have consistently shown that levels of contamination in the environment outside the exclusion areas do not add significantly to normal background radiation. Table 3 gives some indication of how small the radioactive fall-out is from nuclear power stations compared with the natural background radiation from cosmic rays and radioactive sources on land and sea, and from, for example the medical uses of X-Rays.

Table 3

EXPOSURES TO RADIO ACTIVITY FROM MAJOR SOURCES IN CANADA AND GENERALLY ACCEPTABLE LEVELS

Source	Approximate Average Annual Dose (Millirem)
1. Average natural background of radioactivity to which Canadian population has always been exposed	125
2. Man-made source of radioactivity:	
(a) Average chest X-ray	20-500
(b) General medical uses	90
(c) Estimated maximum of radioactivity from nuclear power plants (1972-2000)	1.0
3. Generally accepted guides:	
(a) Occupational exposure	5,000
(b) Sample population group	170

NOTE: One milliren is one-thousandth of a rem, the unit of ionizing radiation giving the same biological effect as that due to one Roentgen of X-rays (the standard unit of dosage used in radiology). In 2 (c) above, it will be noted that the 1.0 millirem is a cumulative figure estimated from U.S. experience. Canadian estimates are somewhat lower.

SOURCE: Derived from "Energy and Environment", G. T. Seaborg, International Journal Environmental Studies, 1972, Vol. 3, p. 305.

Another perspective is offered by the Canadian Nuclear Association which states:

> "Radiation released from nuclear power plants is extremely small. In fact, if a person were to stand at the boundary of such a plant continuously for 365 days of the year, he would receive only about one or two millirem. As a comparison a worker on the 56th floor of the Toronto-Dominion Centre would receive about two millirem more than a worker on the ground floor because of cosmic radiation."

Furthermore, the protective systems built into a nuclear power station such as Pickering and Bruce are such that even an improbable "nuclear accident" would be contained within the environs of the plant, and local environmental contamination would be minimal. The probability of a major incident occurring without forewarning is virtually zero. Computer control, predicated on a fail-safe philosophy, eliminates human reaction times, thereby greatly improving the margin of safety.

Because it is a virtual truism that it is cheaper and more effective to control a pollutant at its source, pollution control is an essential part of the overall planning process. An important aspect of this process is the choice of suitable sites for nuclear power stations. From an environmental standpoint, one objective is to ensure that, for example, in the case of thermal effects which are common to all types of electrical generating stations, the stations are located on the shores of large lakes or rivers. Alternatively, improved technology and lower capital costs in installing cooling towers may reduce our current dependency on these large bodies of water for cooling purposes. As the generation of electrical energy increases over the next fifty years, it will be increasingly important to devise schemes for the utilization of waste energy simply because, apart from environmental considerations, society will be less and less able to afford to ignore this wasted energy.

Storage and disposal of spent nuclear fuel is potentially one of the greatest environmental problems facing the nuclear power industry. In present CANDU stations, spent fuel, which will remain radioactive for thousands of years, is submerged in water-filled storage bays within the nuclear station. Recent announcements by the A.E.C.L. indicate that detached concrete structures, not necessarily near the nuclear power station, will be constructed in Ontario to act as a storage basin for spent fuel. This storage method, as opposed to some American methods of storing nuclear waste in abandoned salt mines, etc., offers the advantages of isolated containment from the environment, continuous radioactive monitoring, and, if necessary, inexpensive retrieval. The potential environmental threat posed by long term storage and disposal of spent fuel may increase as nuclear power in Canada assumes a more important role. Joint efforts by Ontario Hydro and Federal

Government Agencies should be continued, and possibly accelerated, in this area to ensure that we do not bequeath a hazardous "nuclear legacy" to future generations.

Other environmental risks accompany the use of nuclear power in Ontario. Radioactive material must be extracted, refined and transported. The CANDU method of generating electricity requires the use of significant quantities of heavy water. The operation of a heavy water plant involves large quantities of hydrogen sulphide in the "enrichment" process. Dangerous concentrations of this gas in the local vicinity of the plant could occur as a result of a major failure in a critical piece of equipment. While the probability of a major catastrophe is considered to be very low, Ontario Hydro in cooperation with A.E.C.L. has developed a series of corrective measures to minimize any effects and contingency plans to guard against such an event.

As the use of nuclear power expands, greater quantities of radioactive material must be mined, refined and transported. Protective measures are established and imposed in Canada by A.E.C.B. for the extraction, processing and transportation of natural uranium. The Sub-committee on Energy and the Environment has recommended further research and some improved standards in these areas. This Sub-committee was appointed jointly by the Advisory Committee on Energy and Task Force Hydro to provide technical expertise and advice in matters relating to the environmental effects of a wide variety of activities in the energy sector of Ontario. Their report has assisted us in formulating our views on matters of the environment.

Ontario Hydro is constantly monitoring the temperature of water discharged from its nuclear plants. Although there have been no firm conclusions concerning the biological effects of thermal discharges, extensive studies are being conducted which will ultimately be reflected in regulations. Until such time the former Ontario Water Resources Commission and the present provincial Ministry of the Environment has established and enforces minimum standards for cooling waters for nuclear power reactors.

Based on the foregoing, it is our opinion that environmental protection from the effects of Ontario Hydro's nuclear power plants has received greater attention than that accorded any other comparable technology introduced into Ontario in the last thirty years. Notwithstanding, it is clear that the adoption of nuclear power generation on a major scale involves risks which are difficult to identify clearly or to measure precisely. Accordingly we recommend that:

3.1 ***Ontario Hydro, in cooperation with Government agencies, continue to pursue a vigorous program of research and engineering development in environmental and human protection in connection with all aspects of nuclear power plant operation, including the long-term storage and disposal of spent nuclear fuel.***

Cost

Critics of the CANDU program argue that capital costs are higher than for competitive reactors, and that it is consequently an uneconomical alternative. It is important that such statements be analyzed in the context of Ontario Hydro's financial "environment", recognizing that the main criterion must be the unit cost of energy into the power grid, including both operating costs and the recovery of capital costs.

The critical factor in an economic evaluation of generation alternatives is the fixed charge rate on capital, a figure which reflects the cost of new capital to Hydro and which will, in practice, be heavily weighted by the cost of new debt. The fixed charge rate is that value, in discounted cash flow (dcf) analysis, which, when multiplied by the original capital sum will provide a constant annual amount sufficient to recover the capital cost plus interest over the life of the station.

Before turning to a discussion of the unit cost of energy, some comments should be directed to the various components of capital cost. A forecast of the capital cost for Pickering Generating Station—Units 1 to 4, is shown in Table 4 ($370/kW). In a paper presented in an international conference in September 1971, the capital cost (in 1971 dollars) of a 1,000 MW LWR plant in the U.S. for a 1977 in-service date, was estimated to be $323/kW. This was based on an assumed interest rate during construction of 6.5%, an escalation factor of 6.0% per year after the third year and a 10% contingency. A detailed comparative analysis of capital and operating costs is presently being conducted by Ontario Hydro in which the costs of U.S. LWR's are being compared with those of CANDU. The study uses dcf methods of analysis and current costs of capital in a full performance comparison of the two nuclear alternatives over their estimated service lives.

Table 4 illustrates that the nuclear steam supply system for the CANDU system accounts for 30.9% of the total cost (Item 3) made up of hardware (13.7%), fuel (1.2%) and heavy water (16.0%). Interest during construction (13.6%) represents nearly the same proportion of capital costs as all of the nuclear hardware.

Historical experience in the United States has shown that escalation of the cost of labour is one of the most uncertain components of the total cost. Nuclear plant construction craft labour costs in the United States, for example, increased by a factor of 2.5 from 1967 to 1971. Uncertainties regarding escalation in these areas tend to mask any gains that might be achieved in other components such as the hardware for the nuclear steam supply system, which accounts for about 14% of the total cost (excluding fuel and heavy water). Design changes in pumps, heat exchangers, piping and other hardware could result in significant cost savings yet these can be eradicated quickly by cost escalations or construction delays.

The achievement of a degree of standardization in design and size of the units within a nuclear generating station would allow the nuclear supply industry to capitalize on the development and experience gained to date, and begin to effect cost reductions through the learning curve. Any reduction of construction time would have a major impact on costs. Furthermore traditional management practices must be augmented by more efficient methods to handle the information generated, processed and communicated in an environment so dynamic and uncertain.

Table 4

CAPITAL COST OF UNITS 1-4 – PICKERING GENERATING STATION

Direct Costs	Forecast (Thousands) (1971 $)	%
1. Site and Improvements	5,121	0.7
2. Buildings and Structures	73,019	9.8
3. Reactor, Boiler and Auxilliary	102,102	13.7
– Fuel	8,740	1.2
– Heavy Water	119,260	16.0
4. Turbine Generator and Auxilliary	66,172	8.9
5. Electrical Power Systems	32,443	4.3
6. Instrumentation and Control	25,925	3.5
7. Common Processes and Services	32,054	4.3
TOTAL DIRECT COSTS	464,566	62.4
8. Indirect Costs		
– Construction Plant – 1st Cost	5,397	0.7
– Operation and Maintenance	48,353	6.5
– Field Engineering	13,464	1.8
– Accounting	2,483	0.3
– Hydro Engineering	23,872	3.2
– AECL Engineering	36,223	4.9
– Inspection	2,311	0.3
– Commissioning	19,774	2.6
– Administration	14,238	1.9
– Escalation	6,793	0.9
– Interest During Construction	101,788	13.6
– Contingencies	6,748	0.9
TOTAL INDIRECT COSTS	281,434	37.6
GRAND TOTAL	746,000	100.0
Cost per Kw	$370.	

Source: Ontario Hydro – April 1972

Unit Energy Cost

The average annual unit cost of energy for a generating station is the sum of the annual charges for capital recovery, fuel, operation and maintenance, and overheads, divided by the anticipated average annual generation in kilowatt-hours.

Capital Charges

By far the most significant factor in the unit cost of energy is the annual capital charge which is a function of the capital cost of the station, its expected life, and the cost of money. Station life is assumed to be 30 years with an average capacity factor of 80 percent–7,000 hours per year.

For a four unit station, the capital charges on the direct cost for CANDU-PHW, at a 6% interest rate and including the initial charge of heavy water, would vary from 1.96 mills/kWh with each unit rated at 500 MW, to 1.69 mills/kWh with 750 MW units. Under the same conditions capital charges for light water reactors (in U.S. funds) would vary from 1.39 mills/kWh, using 400 MW units to 1.09 mills/kWh with 1,000 MW units.

Fuel

The significant economic feature of CANDU-PHW, as compared with LWR's, is the low fuel cost. Typical fuel costs of LWR reactors are 1.6 mills/kWh, higher than for CANDU-PHW (0.61 to 0.64 mills/kWh) by a factor of 2 or 3. Fuelling costs also depend on the cost of money and for this reason will vary from time to time.

U.S. fuel costs include a credit for plutonium and uranium extracted from the spent fuel, amounting to about 15% of the total cost. Although plutonium could be extracted from spent CANDU fuel, and this will be economically feasible at some future date when the fast breeder demand becomes significant, no credit for plutonium has been included in the above CANDU fuel costs.

Operation and Maintenance

Operation and maintenance costs for light water reactors vary from 0.20 mills/kWh for a four unit station with each unit rated at 400 mW, to 0.12 mills/kWh with each unit rated at 1,000 MW. Operation and maintenance costs for heavy water reactors were estimated at an additional 0.10 mills/kWh to compensate for heavy water losses but, in actual fact, losses at Pickering have been one-half this amount–0.05 mills/kWh. Apart from heavy water replenishment, the major components of operation and maintenance are manpower and materials.

Indirect Costs

Since indirect costs for light water and heavy water reactors have been estimated to be equal on the same size units, they are excluded from this analysis.

The comparative unit energy costs between LWR and CANDU-PHW reactors, with the aforementioned assumptions and excluding indirect costs, are shown in Table 5.

Table 5

UNIT ENERGY COST (mills/kWh–1968 to 7000 hrs/year)
(excluding indirect costs)

FACTOR	LWR	CANDU-PHW
Ranges of reactor unit sizes (MW)	400 – 1,000	500 – 750
Capital charges (@ 6% interest rate)	1.39 – 1.09	1.96 – 1.69
Fuel	1.60 – 1.60	0.64 – 0.61
Operation and Maintenance	0.20 – 0.12	0.28 – 0.25
Total (excluding indirect costs)	3.10 – 2.81	2.88 – 2.55

Source: W. G. Morison, Heavy Water Nuclear Power Stations – The Next Ten Years, Internal Hydro Report II-CA-20, 1968.

The lower fuelling costs of CANDU more than offset higher fixed charges when interest rates are low, but as they rise, LWR's become cheaper. The cross-over point depends on a number of factors. The paper referred to in Table 5 showed the cross-over at a fixed charge rate of 11 percent based on CANDU costs as they were known in 1968. Even though the more recent figures on CANDU-PHW are available, it was not possible to obtain recent data on LWR power reactors that would be as reliable. However, the comparative analysis carried out in 1968 still remains valid because the effects of inflation and of technological progress have been virtually the same for both reactors. In general, CANDU reactors are best suited for utilities that face fixed charge rates less than 11 percent. The necessity to pay taxes and dividends drives the cost of capital upwards, and fixed charge rates of 12-14 percent are not uncommon in the privately owned, tax paying utilities in the U.S. In such cases, CANDU would be economical only if capital costs were substantially lower. CANDU could also be attractive to a regulated utility attempting to increase its rate base, although this does not represent an inherent economic advantage of the system.

While unit energy costs are of prime importance in an evaluation of alternative nuclear power systems, the initial capital costs also can be a significant factor in the selection of a specific system. In practice, there is a limit to the amount of capital that can be raised at any point in time at an acceptable interest rate; in some instances, this could be the principal criterion in the selection process. Thus, in spite of CANDU's lower unit energy cost over the lifetime of the station, the higher initial capital outlay required could be a deterrent to sales if capital is not readily available.

Before leaving the matter of costs, the issue of such major supporting capital facilities as fuel enrichment plants and plants for the production of heavy water should be discussed.

If, in the future, the production of electricity from nuclear power increases as expected, additional major capital expenditures for these supporting facilities must be taken into account in assessing unit energy costs and the availability of capital. For LWR's it is necessary to build capital facilities to supply enriched fuel for each reactor over its life. Accurate costs of these facilities are not available, but conservative estimates suggest the capital cost, in 1972 dollars, for plants which convert uranium to uranium hexaflouride for gaseous diffusion plants to enrich the UF6 and for plants to reconvert to uranium oxide would be at least \$50 for each kilowatt made available to the power grid by the nuclear generating station. To this must be added a cost of about \$25 for each kilowatt made available to the power grid for an electric power station to produce the energy to run the diffusion plant or, totalling the two costs, roughly \$75 for each kilowatt sent out to the grid.

For the current CANDU stations, one ton of heavy water is required for each megawatt of generating plant installed. The estimated capital cost, in 1972 dollars, of heavy water production plants is about \$20 for each kilowatt sent out to the grid plus about \$5 to pay for the capital facilities to provide energy (electricity and steam) to the heavy water production plant— a total of \$25 per kilowatt sent out to the grid.

Capital costs related to the reprocessing of spent fuel may be ignored since in the long run this process also may be desirable in the CANDU system.

Thus the difference between the LWR and CANDU in capital required to install a megawatt of generating capacity is insignificant if all capital expenditures are taken into account. See table 6.

The fixed charges on these capital costs (enrichment facilities and heavy water plants) appear in the fueling cost of the LWR's and in the heavy water cost for the CANDU. Furthermore, the capital and production costs for an enriched fuel, are more uncertain than for natural uranium and heavy water.

Table 6

CAPITAL COSTS PER KILOWATT OF CAPACITY (1972)

FACILITY	LWR	CANDU
Nuclear Generating Station	$323	$370
Enrichment Facilities	75	–
Heavy Water Plant	–	25
TOTAL	$398	$395

SECTION V

FUTURE NUCLEAR POWER PROGRAM OF ONTARIO HYDRO

We began this Study by accepting two important assumptions, that the demand for electricity would continue to rise, and that an increasing proportion of our requirements would be met through nuclear generation. Our investigation has convinced us that Hydro's decision in the early 1950's to develop a nuclear alternative was as wise as it was courageous, for two important reasons:

- by relying on uranium, an indigenous resource, Ontario's independence is reduced on fossil fuel supplies over which it has virtually no control
- nuclear generation offers the best alternative currently available in meeting environmental standards especially on quality standards.

With respect to the alternatives shown in Figure 1, as these relate to the choice of fuel cycle and coolants, we feel that Ontario Hydro's unwavering confidence in CANDU merits continuing support. On the basis of our assessment of the issues, reliability, capital costs, the unit cost of energy and environmental impact we feel that CANDU is particularly well suited to Ontario's needs. Its technical qualities are being recognized by experts in other countries and appear to be borne out by recent operating experience. Its low operating cost, based on burning natural uranium is of particular significance to Ontario.

We therefore recommend that:

3.2 ***Nuclear power stations be of the CANDU-PHW type unless future studies and assessments reveal that some alternative type will more closely meet the needs of the Province of Ontario.***

The arguments on reliability suggest that there should be a conservative approach to design changes and the introduction of major concepts within the CANDU family such as the OCR, BLW, and others. The accumulation of operating experience with PHW reactors will result in the development of confidence and will confirm the design as reliable for long term operation. Furthermore, repetitive manufacture lowers unit costs.

Therefore we recommend that:

3.3 ***In recognition of the need to gain more operating experience and confidence with existing types of CANDU reactors and more knowledge of the economies of multiple unit manufacture, changes in design and type be resisted unless clear economic advantages can be demonstrated.***

We note the recent decision to construct a CANDU PHW reactor Gentilly II in Quebec, combining advanced features of the 750 MW Bruce units with the operational experience of the 500 MW units at Pickering. Here it seems, we have lost an opportunity to take advantage of lower costs through multiple manufacture. Furthermore we appear to be spending money to produce a unit of lower capacity than those now under construction at Bruce. We stand therefore to gain nothing in terms of economies of scale.

All of the foregoing is not intended to suggest that Ontario Hydro should terminate studies of alternative and competitive reactor types. Continuing assessments are essential, if only to maintain current awareness of new developments and to evaluate operating experience with alternative types. Furthermore, there is a need to consider potential successors to the PHW reactor in the continuing evolution of nuclear power systems. Ontario Hydro should continue to cooperate with A.E.C.L. on the testing of the CANDU-BLW at Gentilly, Quebec, and with A.E.C.L. in studies of CANDU-OCR at the Whiteshell Nuclear Reactor Establishment in Manitoba.

We recommend that:

3.4 Ontario Hydro continue the assessment of other nuclear power reactors.

While the principle conclusions are woven into 20 specific recommendations, it is our major conviction that Ontario Hydro persist with the CANDU family of reactors, and that no effort be spared to expand sales of CANDU installation to other provinces and abroad.

Long Term Arrangements Between A.E.C.L. and Ontario Hydro

The impressive achievements in the Canadian nuclear power program have been due in no small measure to the close collaboration between Ontario Hydro and A.E.C.L. The NPD, Douglas Point and Gentilly reactors are owned by A.E.C.L. and the continuing research and development related to these reactors can be expected to be undertaken by A.E.C.L. Short term applied research and development work for Pickering and Bruce is conducted at Chalk River, Whiteshell and Sheridan Park and is at least partly paid for by Hydro under a sharing arrangement. An agreement on cost sharing is formalized following discussion of the need for each development project. For projects directly related to Pickering or Bruce, Ontario Hydro pays 100%; for others the percentage may be as low as 25%.

There are no formal arrangements for fundamental or basic research on power reactors. At present, it is tacitly understood that A.E.C.L. will continue to conduct such research work as a support for on-going nuclear power programs. These research activities can be regarded as "open-

ended" although it is expected that the work on pressurized heavy water systems should diminish over the next several years. Because these basic research efforts are appropriate to Canada's nuclear power program as a whole and the objectives of Ontario Hydro as an electrical utility may not always coincide with those of A.E.C.L., it is believed that basic research should be a federal government responsibility. But, the A.E.C.L. and Ontario Hydro association is so important that there should not be any risk of possible varying interpretations in the future. The arrangements should be more formalized and therefore we recommend that:

> *3.5* **The existing arrangements under which A.E.C.L. undertakes *basic research in support of the nuclear power program of Ontario Hydro should be replaced with formal agreements.***

In considering the possibility of CANDU reactor sales to other provinces and abroad, the requirements may be such that a Pickering or Bruce design, or a portion thereof, would be entirely suitable. In this case, considerable cost savings would be achieved by using the existing designs, drawings, reports and manuals from these generating stations. They have been developed at the expense of Ontario Hydro and there should be arrangements whereby they can be purchased or licensed from Hydro by A.E.C.L. Ontario Hydro should receive a royalty for the use of such material. For this reason, we recommend that:

> *3.6* ***There be agreements between A.E.C.L. and Ontario Hydro relating to the sale by A.E.C.L. of designs, drawings, reports and manuals of Hydro's nuclear generating stations.***

SECTION VI

RESOURCES AND MARKETS

Energy is a critical resource. In a major energy crisis the security of supply of vital materials and resources becomes paramount. The objectives of Ontario Hydro include satisfying the future demand for electrical energy safely, reliably, and economically with proper regard for the environment. We believe a strong case has been established for pursuing the nuclear alternative based on economics, the relative abundance of energy sources and the relative environmental impact. For the nuclear option, the following issues have a direct bearing on security: fuel, heavy water, and design and construction.

Nuclear Fuel

As indicated in Table 7 Canadian natural uranium deposits are extensive, constituting roughly 20 percent of the reserves in the Western World. More than 80 percent of our known reserves are contained in the quartz-pebble conglomerates of Huronian age in the Elliot Lake and Agnew Lake areas of Ontario, the remainder lying in pitchblende bearing vein-type and related deposits which occur primarily in Saskatchewan. For mines now in operation, the Ontario reserves are of lower grade but of more massive proportions and appreciably cheaper to mine. Only a fraction of Canada's low-cost uranium reserve (less than $10 per pound) is at present committed and the unexplored potential is extensive. Expert geological opinion predicts the discovery of significant additional deposits of uranium ore in Canada.

Until recently, with an annual production of 5000 tons of uranium concentrates Canada was supplying about 20 percent of the Western market. Up to 1972 total Canadian production has been estimated at some 125,000 tons. To supply the same percentage in 1980 Canada would need to produce about 15000 tons per annum, a figure substantially in excess of current capacity. Since it takes from 8 to 10 years from the start of exploration to establish a producing mine there is already a need to begin new exploration.

The anticipated future demand for uranium in the United States and for the Western World on both an annual and a cumulative basis is indicated in Table 8. Comparison of these data with those in Table 7 indicate that if one takes into account reasonably assured deposits and estimated additional reserves in both the under $10 per pound and the $10-15 per pound category, there will be a slight excess of supply over demand by the year 2000. Such an optimistic picture may explain the fact that none of the organizations visited by our Nuclear Power Project Team in the United Kingdom, France and the United States expressed any concern about the future availability of uranium. We are not so sure.

We note that the decline in demand between 1990 and 2000 is predicated on the assumption that breeder reactors will be in comparatively widespread use during that decade. In the opinion of many experts such an assumption is unduly optimistic and therefore the demand data shown in Table 8 must be regarded as expressing minimum requirements.

Table 7

Uranium Resources in Western WORLD
(in thousands tons U_3O_8)

	Less than $10/lb		$10 - $15/lb	
	Reasonably Annual	Estimated Additional	Reasonably Annual	Estimated Additional
Canada	236	240	158	276
United States	333	650	177	350
South Africa	200	15	65	35
Australia	92	102	38	38
Others	279	3	413	9
TOTAL	1140	1100	851	858

Source: Department of Energy Mines and Resources 1972.

Table 8

FUTURE DEMAND FOR URANIUM
(Demand of U_3O_8 in 1,000's of tons)

Year	Western World		United States	
	Annual Demand	Cumulative Amount	Annual Demand	Cumulative Amount
1971	15,000	15,000	7,500	7,500
1972	21,000	36,000	10,200	17,700
1973	26,700	62,700	14,700	32,400
1974	31,500	94,200	18,200	50,600
1975	38,700	132,900	20,100	70,700
1976	45,900	178,800	23,000	93,700
1977	52,200	231,000	26,600	120,300
1978	59,600	290,600	31,200	151,500
1979	67,900	358,500	34,600	186,100
1980	76,100	434,600	37,300	223,400
1981	85,000	519,600	42,800	266,200
1982	95,000	614,600	48,300	314,500
1983	106,000	720,600	53,500	368,000
1984	117,000	837,600	58,800	426,800
1985	130,000	967,600	64,300	491,100
1990	193,000	1,806,600	96,500	908,600
1995	171,500	2,707,100	85,700	1,358,100
2000	123,500	3,422,300	61,700	1,714,600

Sources of Data:

(Based on "Uranium Supply and Demand" – D.S. Robertson & Assoc. Ltd. report to A.C.E.).

Western World Demand:

1. To 1985 – "Uranium – Resources, Production and Demand" Joint Report of European Nuclear Energy Agency and International Atomic Energy Agency, Sept. 1970 (with all figures to 1980 revised to include latest US projections, and with interpolation between 1971 and 1985).
2. 1985-2000 estimated at twice U.S. damand.

United States Demand:

Remarks by Wilfrid E. Johnson, Commissioner
USAEC – American Mining Congress, Las Vegas,
Nevada, Oct. 13, 1971.

Lack of concern about uranium supplies also stems from current stock piles of uranium and estimates of production capacity in relation to present demand. We are informed that this is a short term situation; by 1976 US demand will balance the supply, and thereafter demand will not be met through existing facilities. There will inevitably be delays in bringing new mines into production which could lead to temporary shortages and rising prices within the relatively near future.

If we assume that Ontario Hydro will have a nuclear power capacity of 18,000 MW in service by 1990 and 30,000 MW by 2000, the annual demand for natural uranium assuming CANDU systems are used, would be roughly 3000 tons by 1990 increasing to 5000 tons in the year 2000. Put another way, it has been estimated that Canada's accumulated requirements during the period 1973-2000 will approach 100,000 tons of U_3O_8 of which some 80 percent would be needed by Ontario Hydro.

It is important to ensure that adequate supplies have been reserved at reasonable prices, to satisfy the needs of Ontario Hydro and for Canada as a whole. By March 1970, Canadian producers had committed 55,000 tons of U_3O_8 of which 86 percent was for export. Late in 1970 Gulf's Rabbit Lake facility guaranteed to supply West Germany with 2000 tons of U_3O_8 a year, totalling 40,000 tons by 1995. Even though these data must be regarded as rough approximations, it may be concluded that:

- Canadian uranium, major amounts of which are in Ontario, will be an increasingly important natural resource and there is little doubt of increasing pressures on reserves, probably before 1990.

- there is every likelihood of temporary shortages and rising prices within this present decade due to delays imposed by the current lack of exploration.

It is obviously important therefore that steps be taken to reserve, assure and secure adequate supplies of natural uranium to satisfy the demands of Ontario Hydro until the year 2000 and beyond.

Accordingly we recommend that:

3.7 Formal steps be taken through contractual arrangements to ensure that Ontario Hydro has an assured supply of natural uranium to meet the potential requirements of its nuclear power program, up to at least the year 2000.

As one means of securing adequate nuclear fuel supplies at a relatively low cost we suggest that Hydro might give consideration to acquiring control of a uranium mine complex.

Facilities exist in Ontario to process ore, through to production of uranium dioxide pellets, thence to fabrication of fuel bundles. The only major refining facility for treatment of concentrated uranium ore is Eldorado's Port Hope refinery. Current production of U_3O_8 for Ontario Hydro is about 400 tons of uranium a year, and this will probably rise to about 1,000 tons a year by 1980. There has been a surplus of fuel manufacturing capability in Canada during the past five years which should secure Ontario Hydro's position in the face of the anticipated growth of nuclear power during the next two decades.

Heavy Water

An assured supply of heavy water is as critical as an assured supply of fuel if electricity is to be produced by the CANDU method. For each megawatt of nuclear capacity committed, about one ton of heavy water is required for the initial charge. This means that expansion of heavy water production facilities must take place at the same rate as increases in the commitments of CANDU nuclear stations.

When the presently committed Canadian heavy water plants at Glace Bay and Point Tupper in Nova Scotia and the Bruce plant in Ontario are all in full operation, the total potential output will be about 1,600 tons per year. Allowing for a 70% capacity factor this will be just enough to cope with Ontario Hydro's present generating capacity growth of 1,200 MW per year. But the demand for heavy water will not be restricted to Ontario. As CANDU systems are installed in other provinces and other countries there will be competing demands for existing heavy water production facilities. Despite assurance from A.E.C.L. that present shortages are temporary and that adequate heavy water production in Canada will be achieved by 1975, Canada has yet to demonstrate the ability to produce adequate quantitites of heavy water.

Accordingly we recommend that:

3.8 Appropriate steps be taken to ensure that adequate heavy water is available in time to satisfy Ontario Hydro's planned CANDU nuclear program and to support the further commitment of CANDU reactors in Ontario and elsewhere.

It has been the uncertainty surrounding the supply of heavy water which has caused Ontario Hydro to delay a commitment for further CANDU generating stations. Certainly the current shortage has delayed the present construction program including Pickering 4 and Bruce. These conditions lead Hydro to initiate planning for the Bruce heavy water plant which is now being constructed by A.E.C.L. and is to be operated by Hydro. The facility has been designed to accommodate 2 additional units which would provide a total capacity of 1600 tons per annum. Hydro estimates that using the same

designers and constructors these additional units could begin to produce heavy water in 42 months and be in full production in 5 years from the date of commitment providing orders were placed immediately. Using inexperienced designers and construction forces would delay the project an estimated 2-1/2 years.

As long as these conditions persist, we recommend that:

3.9 ***Ontario Hydro give consideration to constructing and operating heavy water production facilities adequate to assure its own supplies.***

This would be an excellent opportunity to consider a joint venture between Ontario Hydro and the private sector. Through such an arrangement a vital short term supply problem could be solved, and an important technical capability transferred to the private sector.

Design and Construction

Fuel and heavy water supplies are crucial to the security of CANDU nuclear power systems but the technology, skilled manpower and necessary capital facilities required to fabricate and operate such generating stations, though less apparent, are no less significant. Of particular importance is the engineering and management capability required to design, procure and supervise the fabrication of new stations. It has been Ontario Hydro–A.E.C.L. policy to develop this capability in-house. In this way it is argued that greater efficiencies accrue, due to closer lines of command and communication between and among all aspects of generation and distribution. The success so far has been due in large measure to this close cooperation over the past 15 years. Favourable comments have been made by others on the "singleness of purpose" of the Ontario Hydro-A.E.C.L. "team" and to this is attributed much of CANDU's success.

An important problem arising from Hydro's in-house policy lies in dealing with the long intervals between construction of successive generating stations. Aside from the particular problems of the supply industry cited below, retaining the teams of experts within Hydro and A.E.C.L. during the "valleys" is crucially important and can become extremely expensive. The use of outside consultants could be one solution to the problem, but during the "valleys" there is no assurance that the consultant teams will remain intact unless there is work from beyond the Ontario borders. From the standpoint of security the important consideration is not whether these skills are in-house or outside but that needed skills should remain accessible to Ontario Hydro. Task Force Hydro is investigating 'Make or Buy' aspects of Hydro's operations. The findings of this study could have an impact on the future development of in-house engineering design and management capability related to nuclear power generation.

The continuing viability of the nuclear supply industry is also basic to the development of nuclear plants in Ontario. The consensus of key representatives of several major heavy equipment suppliers appears to be that the industry will not be viable if less than two reactors per year are manufactured (Ontario Hydro has brought at least two 500 MW units into service in each of the last three years). In addition, it was suggested that a planning horizon of 7 or 8 years would permit better planning of financial and manpower resources. Again, Hydro has such a planning horizon. But suppliers do not feel that they have sufficient access to Hydro's intentions to permit them to plan effectively. The industry is not solely dependent upon Canadian orders as several suppliers could provide components for reactors other than the CANDU, though quantity orders would be required to justify the needed capital expenditures.

When CANDU reactors are built by other than Hydro it would be reasonable to anticipate that A.E.C.L. would be the nuclear designer, the conventional engineering contracted to a private engineering consulting group and the construction contracted to a local company. In view of the importance of building up a strong CANDU component in the total world nuclear power scene, we believe that it is important for Ontario Hydro to facilitate CANDU programs, even outside the province, as much as practicable.

Since Ontario Hydro is the only utility with operational experience with CANDU-PHW power systems, it would be virtually obligated to provide expert support personnel and training facilities when CANDU power plants are built in other provinces and abroad. Hydro's facilities for training operational personnel are extensive, expensive and unique; it is crucial that they be made available for the training of key operational personnel. Experienced personnel to assist in the start-up of nuclear plants elsewhere in Canada and abroad presumably could be spared for limited periods without prejudice to Hydro's own operations.

We recommend that:

3.10 Ontario Hydro support the design, construction, and operation of CANDU reactors outside its own system by making available on reasonable terms experienced personnel but not to an extent that would prejudice its own nuclear power program.

We further recommend that:

3.11 Ontario Hydro explore the possibility of joint ventures with private enterprise to further other sales of CANDU.

Each year the United States military gives a complete and detailed briefing to its suppliers that they might be fully informed on the plans and expectations in the coming year.

Since it is in the interests of Ontario Hydro that a viable supply industry be maintained, and since the industry needs some form of planning horizon upon which it can base its financial and manpower plans, and since the industry appears to be uninformed as to Hydro's long term plans, it is recommended that:

3.12 Ontario Hydro arrange annual briefing sessions to inform the industry concerning its nuclear power program.

Development of Foreign Markets

Our discussions with nuclear experts in other countries raised vitally important questions regarding the future of CANDU as a viable nuclear power system for the future. Many felt that without foreign markets, no single country could afford the continuing costs associated with the development of such a highly sophisticated technical enterprise. The United States and Russia are two exceptions. We are therefore led to the conclusion that everything possible should be done to develop a foreign market for CANDU. So far, in spite of A.E.C.L.'s best efforts, no foreign sale[3] has yet been made. A number of factors could have contributed to this lack of success.

- The limited operating experience relative to that for competing systems has been difficult to overcome.

- A.E.C.L.'s marketing effort may have been subject to relatively rigid terms of reference when maximum flexibility is required to compete in international markets.

Notwithstanding, conditions are changing so that the balance could be shifting in our favour. Pickering's recent performance and encouraging reports on the Bruce heavy water plant could provide, within the next few months, clear evidence of the technical excellence and dependability of CANDU. Now is the time it seems to follow up our technical success with a redoubled marketing effort. Foreign sales of CANDU, as we have pointed out, are of vital concern not only to Ontario but to the whole of Canada.

We therefore recommend that:

3.13 The Federal Government be urged to expand its campaign to sell CANDU reactors in Canada and abroad making use of all resources available not only within its own jurisdiction but also those in Provincial Governments and the private sector.

3. The announcement, in March 1973, of the sale of a 600 MW CANDU-PHW reactor to Argentina has changed this situation.

The CANDU system, because of its low cost fuel cycle, could be made particularly attractive to prospective foreign purchasers if they were assured of a long-term supply of fuel at a reasonable cost. The future price of enriched uranium is relatively uncertain due to the need to include fixed charges associated with the massive capital expenditures involved. An assured supply of heavy water along with a contract for low cost natural uranium could further strengthen CANDU's competitive position relative to alternative systems. Thus we recommend that:

> 3.14 ***The Federal Government be urged to examine the feasibility of offering long term fuel and heavy water supply contracts to foreign purchasers as an added incentive to buy CANDU reactors, subject to a requirement for security of domestic supplies and present commitments.***

SECTION VII

EDUCATION AND INFORMATION

Education

The development of a nuclear power program in Canada will depend on an adequate supply of persons competent to deal with the design, engineering and operation of nuclear power plants. Currently the key institutions for the training of people in the technical and operational aspects of nuclear power generation are the Nuclear Training Centre (NTC) and the adjacent Nuclear Power Demonstration (NPD) reactor at Rolphton, near Ottawa, and the Pickering Nuclear Generating Station. The total instructional staff at Rolphton is approximately 40, supplemented by four instructors who direct the in-plant training at Pickering. The NTC includes excellent, modern laboratories while NPD provides facilities for an operational type of training. The NTC facilities have been used for training Ontario Hydro employees, technical personnel from the Gentilly Nuclear Power Station and operators from the RAPP and KANUPP plants. By the end of 1972, more than 1300 persons will have received significant technical training at these institutions in such areas as:

Basic science fundamentals
Equipment and systems principles
Welding and machine practice
Radiation and conventional safety.

The length of the training period can vary widely. The basic training of the technical staff ordinarily takes six to nine months but the total training period, for an entrant into the program taking on increasing responsibilities, is likely to be six years and may be substantially more. In addition to the academic and practical knowledge gained in this program, A.E.C.B. requires certain key operational personnel to obtain special qualifications in the areas of protection and safety.

In a dynamic field such as nuclear technology, it is surprising that there are so few university courses in Canada in nuclear engineering, in contrast, for example, with the comparatively large number of courses in nuclear science. Yet there is a clear need to extend expertise in nuclear technology well beyond the confines of A.E.C.L. and Ontario Hydro. The importance of this will grow as the commitment to the generation of power from nuclear sources is extended. Although on-the-job training and education in Hydro (and A.E.C.L.) plants and laboratories, coupled with the NTC programs, are excellent insofar as the requirements of skilled personnel for current and foreseeable future operations are concerned, it is clear that in the long run Canadian nuclear power programs will suffer unless institutions of higher education become more involved with nuclear engineering. This involvement needs to be supported by a strong research program.

The universities should be encouraged to arrange special short courses in such areas as the production of heavy water, the mining and fabrication of nuclear fuel, the management of nuclear power stations, and the prospects for fusion power. A systems engineering orientation is necessary in the overall design of complex systems such as a modern nuclear power station. In view of the fact that the computer has transformed systems engineering, especially in the field of simulation, and in view of the advent of relevant operations research methods, the universities should also be encouraged to provide appropriate courses in these areas for modern orientation of nuclear engineers. To facilitate educational programs in nuclear power, we recommend that:

3.15 ***Programs in applied science and engineering related to nuclear technology be established in selected universities and colleges within Ontario.***

In view of the extensive post-secondary educational facilities in Ontario it might be feasible eventually to provide the necessary basic science and engineering courses in, for example, the universities and the Colleges of Applied Arts and Technology, and to restrict activities at NTC to training essentially through exposure to plant conditions which would be supplemented by on-the-job training. With the expected increase in the number of trained personnel required it will become necessary to optimize the use of the unique facilities at Rolphton. To this end we recommend that:

3.16 *(a)* ***Ontario Hydro's Nuclear Training Centre offer selected employees of Canadian utilities and the Canadian nuclear industry short courses of two to four weeks duration in nuclear power technology, with special reference to CANDU systems.***

(b) ***The possibility of the Nuclear Training Centre becoming part of the Ontario educational system be considered.***

One way of ensuring an appreciable strengthening of nuclear engineering in the Ontario universities would be to arrange for the appointment of applied scientists from A.E.C.L. and Hydro as part-time lecturers in the universities and community colleges. Fortunately, the statutory machinery for facilitating the release of information and the encouragement of education in nuclear science and engineering is already embodied in the Atomic Energy Control Act, in relation to the dissemination of information and the establishing of scholarships and grants to promote research and training of personnel.

Information, the Policy Makers and the Public

The far reaching issues which relate to the growth of nuclear power in Ontario demand that the policy and decision makers have a basic understanding of the role of nuclear power in the generation of electricity and particularly are aware of the alternative nuclear programs that could be pursued. This understanding should be based on diverse points of view—engineering, legal, health, economic, and the like.

The original A.E.C.L. symposium on atomic power was designed to keep federal and provincial policy makers up-to-date on nuclear power developments. About 13 such symposia have been held since 1953, the last one being in 1968. In technical terms the papers were at the intermediate level and were probably not fully understood by the predominantly lay audiences.

The need for policy makers to understand nuclear power is growing more acute, given that by the end of the century some 50 percent of electrical generating capacity in Ontario is expected to be nuclear with all the implications this carries for capital costs and environmental concerns. If properly planned and the material appropriately prepared, there need be no serious problem in understanding the information that is important to the policy maker.

It is recommended that:

3.17 ***To enhance the detailed knowledge of senior government personnel and industrialists with respect to nuclear power generation and to encourage dialogue between policy makers and nuclear scientists, short symposia be sponsored and organized by the Provincial Government and Ontario Hydro.***

The Public Relations Division of Ontario Hydro is responsible for informing the general public on nuclear power developments in the province. Many of the specific activities are undertaken in collaboration with A.E.C.L. and the Canadian Nuclear Association (CNA). The question as to how to keep the public in touch with technological developments and their possible implications is a crucial issue facing Canada and all other industrialized societies.

The major activities of Ontario Hydro in the nuclear power public information program include booklets and pamphlets dealing with all phases of nuclear power and special programs developed in collaboration with the Ontario Department of Education and based, for the most part, on films and talks. These activities also include information centres at the nuclear generating stations (Pickering and Bruce).

To facilitate the education of the general public in nuclear power matters, the CNA has set up a Public Relations Committee—one of the most active in the Association. In cooperation with Ontario Hydro, the Association arranged a nuclear power symposium for high school science teachers. The Association, again in collaboration with Ontario Hydro, is arranging a special nuclear power workshop for editorial writers to ensure that they are current in their knowledge of nuclear power matters.

But, in spite of these efforts to provide a broad public understanding of the role of nuclear power and the progress of developments in Ontario, a large majority of the citizens of Ontario have no real knowledge of nuclear power. They are sceptical or indifferent and many are even hostile as to the essential role of nuclear power in the economic life of Ontario and its importance as a future source of electrical power.

The problem may be compounded by the fact that even in policy areas where public concern might be anticipated, the public is not brought into the decision making process at a sufficiently early stage. In the words of the petition submitted to the Premier of Ontario on March 27, 1972, by the "Coalition of Concerned Citizens" with respect to the proposed 500-kilovolt transmission line from Pickering to Nanticoke:

> "Before the decision is taken concerning the type and location of transmission systems they (other modern democratic countries) establish Boards and Commissions and hold full public inquiries with unbiased judges in order to reduce these hardships to an acceptable minimum."

We have already recommended in our first two reports that the public should be involved at an early stage in the decision making process and, where feasible, relevant information should be made available, particularly in cases where alternatives exist and there might reasonably be expected to be valid differences of opinion as to which alternative would best serve the public interest.

In the supply area there has been too little public information with respect to the availability of heavy water. Over the next two or three years there may be a serious shortage which would have implications with respect to the nuclear power generating system. If steps being taken are not known and understood it could undermine public confidence in the entire nuclear power program. Full and frank reports must be made on a reasonably continuous basis.

Keeping the public informed of current and potential technological developments related to all aspects of nuclear power generation is profoundly important. To date, especially in the nuclear power area, the use of the media has been minimal except perhaps for the efforts of the Ontario Educational Communications Authority (Television Channel 19). One of the

major difficulties for the media in presenting the "nuclear story" is that scientific and technological language must be translated into language understandable by the general public.

We are of the opinion that it is critically important that the public become increasingly literate in the area of nuclear power generation and all the associated considerations and we hold the view that such literacy, in this area, does not presently exist.

We recommend that:

3.18 Ontario Hydro assume the initiative in the design and implementation of a major and sustained public information program related to nuclear power generation in order to improve the public's knowledge of nuclear technology and enhance its appreciation of the importance to the economy of Ontario of the effective exploitation of nuclear energy.

SECTION VIII

SUMMARY OF RECOMMENDATIONS

REPORT NUMBER ONE: HYDRO IN ONTARIO – A FUTURE ROLE AND PLACE

Task Force Hydro recommended that:

HYDRO'S ROLE

1.1 (a) Ontario Hydro be responsible to the Government of Ontario for the generation, transmission and distribution of electric energy in the Province.

(b) Ontario Hydro discharge this responsibility in compliance with the overall policy of the Provincial Government.

(c) Except where economic considerations dictate otherwise Ontario Hydro delegate its responsibility for the distribution of electric energy to utilities that are agents of municipalities.

1.2 Hydro be a delivery agency of the Provincial Government receiving broad policy direction from the Government through the Provincial Secretary for Resources Development.

1.3 Hydro be directed through the Provincial Secretary for Resources Development:

(a) to meet demand for electricity in Ontario at the lowest feasible cost.

(b) to maintain those standards of reliability which are agreed upon from time to time by the Government and Hydro.

1.4 Hydro exploit its technology through developing and pursuing policies to share its technological expertise with the private sector.

1.5 As a general rule, the additional costs incurred for environmental concerns be included in electricity prices.

1.6 *Hydro actively participate in the development and support of Government policies with respect to energy and the environment.*

1.7 *Hydro's marketing policy be designed specifically to support Provincial energy and environmental policy and, within the limits thereby imposed, to ensure the most efficient use of the system's capital facilities.*

1.8 *There continue to be close coordination between Hydro and the Ministry of Treasury, Economics and Intergovernmental Affairs in financial matters.*

1.9 *In the event that Hydro should be required to support regional development or contra-cyclical construction policies, the additional costs of so doing should not be built into power prices but should be borne by subsidy from the Provincial Treasury.*

HYDRO AND THE PUBLIC

1.10 *Hydro establish a procedure whereby representations and appeals from the public can be heard by a body responsible to the senior policy making body of Hydro but not a part of the line organization.*

1.11 *There be no requirement for the consent of the Minister of Justice and Attorney General to bring an action against the Hydro Commission or any member of the Hydro Commission.*

1.12 *Hydro consider the establishment of ad hoc citizens' task forces to provide for citizen participation in the locating of generating and transmission facilities and in other matters of concern to the public.*

1.13 *Responsibility for the establishment of electrical safety standards be transferred to an agency of the Ontario Government other than Ontario Hydro, but responsibility for the actual inspection function continue to rest with Hydro.*

HYDRO AND THE PROVINCIAL GOVERNMENT

1.14 Government policy, defining the broad objectives and constraints within which Hydro must operate, be specified by the Lieutenant-Governor in Council.

1.15 To give expression to Government policy for Hydro and to define Hydro's mandate, a contract be drawn up between the Provincial Government and Hydro.

1.16 Government policy for Hydro that is not defined by Orders-in-Council or by the Government-Hydro contract be determined by the Provincial Secretary for Resources Development in consultation with the senior policy body of Hydro.

1.17 Hydro be directed to pursue other objectives which may be established from time to time by the Lieutenant-Governor in Council.

CORPORATE STRUCTURE

1.18 Ontario Hydro be designated as a Crown Corporation to be known as the Hydro Corporation of Ontario or Ontario Hydro.

1.19 The Board of the Hydro Corporation be empowered to deal with the Government on behalf of the total delivery system so as to facilitate consistent policy direction for the total system.

1.20 The Hydro Corporation Board consist of eleven members appointed by the Lieutenant-Governor in Council as follows:

- *a Chairman, for a five year term, renewable*
- *the President of the Hydro Corporation, ex officio*
- *two representatives from nominations submitted by the Board of Directors of the Ontario Municipal Electric Association, for three year terms, twice renewable.*
- *two senior civil servants*
- *five members-at-large to be named from outside the delivery system and government and to be selected for expertise in industrial, corporate, economic or other matters relevant to Hydro, appointed for three year terms, twice renewable.*

1.21 *The Chairman be appointed on a full time basis and his orientation be outward to the Ontario community and to the Government and that, with his Board, he focus on the translation of Government policy into consistent and achievable corporate objectives and policies.*

1.22 *The President be responsible to the Board of Directors for directing the affairs of the Corporation in accordance with goals and objectives established by the Board.*

HYDRO AND THE UTILITIES

1.23 *Ontario Hydro be directly responsible for the management of that part of the delivery system which generates and transmits bulk power.*

1.24 *The division of responsibility between the wholesale and retail functions be drawn at the main secondary bus-bar of the transformer station.*

1.25 *Municipal utilities be rationalized into upper tier regional utilities where and as new municipal government is implemented.*

1.26 *The area to be served by the regional utility be the entire area served by the new municipal government.*

1.27 *A first step toward rationalization encompass those areas of the Province that now have new municipal governments, with the experience thus gained to guide future steps.*

1.28 *Those responsible for planning the rationalization of the retail system attempt to achieve some rationalization of utilities which do not lie within areas soon to be under the jurisdiction of new municipal governments, including the private utilities.*

1.29 *The commissioners of regional utilities be appointed by the municipal council from outside the council with the exception of the chairman of the council who shall be a member ex officio of the commission.*

1.30 *The Hydro Corporation give effect to its policy and that of the Provincial Government through contracts with each utility, such contracts to reflect a working agreement between the Corporation and the utility.*

OWNERSHIP

1.31 *Control and ownership of the Hydro Corporation continue to reside with the Government of Ontario, but the interest of the municipalities be established and defined as follows:*

- *An equity account be established on the balance sheet of the Hydro Corporation as an item to replace the "equities accumulated through debt retirement charges" and certificates be issued to the participating municipalities and to the Corporation as trustee for the power district for their proportionate shares therein.*

- *The certificates be described as non-voting participating shares in the equity account of the Hydro Corporation (equity account shares) and new certificates be issued annually to represent the changing interests of each participating municipality and the rural power district in the same manner as the debt retirement charges have been apportioned annually in the past.*

- *The certificates entitle each participant holding such certificates to receive on the liquidation or winding up of the Hydro Corporation a share proportionate to the dollar amount of the certificates held of the surplus funds realized on liquidation after payment or provision for payment of all debts and obligations of the Hydro Corporation.*

ORGANIZATION

1.32 *Once the Government has established a redefined mandate for Hydro the senior governing body of Hydro require management to submit for its approval a detailed plan and timetable for an approach to organization.*

REPORT NUMBER TWO: HYDRO IN ONTARIO – AN APPROACH TO ORGANIZATION

Task Force Hydro recommends that:

INTERIM ORGANIZATION

2.1 *The organization concepts developed by Task Force Hydro's Organization Study Team be adopted by Hydro as an approach to organization in fulfillment of the new role and place as approved by the Government of Ontario.*

2.2 *As an initial step toward a new organization, Hydro establish a Corporate Office and a Divisional structure based on the four missions identified by the Organization Study Team, viz; Design and Construction, Generation and Transmission, Distribution, and Supply Services.*

APPROACH TO A NEW ORGANIZATION

2.3 *Hydro initiate further studies, using external resources where necessary, to plan the organization structure best suited to its new Role and Place and to develop the highest possible level of productivity and efficiency.*

PUBLIC RESPONSIVENESS

2.4 *Hydro establish an Office of Public Affairs headed by the Director of Public Affairs responsible to the Board for hearing grievances relating to services to the public rendered by Hydro and the distribution utilities.*

2.5 *The Director of Public Affairs place himself at the disposal of members of the Legislature to ensure rapid and effective response to questions and complaints submitted by constituents about Hydro or the distribution utilities.*

2.6 *Ontario Hydro planners, in collaboration with Government at the provincial and local levels and with interested individuals and citizen groups, develop an open planning process to produce economically and technically feasible plans for transmission and generation facilities acceptable to the public and with minimum adverse environmental impact.*

REPORT NUMBER THREE–NUCLEAR POWER IN ONTARIO

Task Force Hydro recommends that:

ENVIRONMENTAL QUALITY IMPLICATIONS

3.1 Ontario Hydro, in cooperation with Government agencies, continue to pursue a vigorous program of research and engineering development in environmental and human protection in connection with all aspects of nuclear power plant operation, including the long-term storage and disposal of spent nuclear fuel.

FUTURE NUCLEAR POWER PROGRAM FOR ONTARIO

3.2 Nuclear power stations be of the CANDU-PHW type unless future studies and assessments reveal that some alternative type will more closely meet the needs of the Province of Ontario.

3.3 In recognition of the need to gain more operating experience and confidence with existing types of CANDU reactors and more knowledge of the economies of multiple unit manufacture, changes in design and type be resisted unless clear economic advantages can be demonstrated.

3.4 Ontario Hydro continue the assessment of other nuclear power reactors.

3.5 The existing arrangements under which A.E.C.L. undertakes basic research in support of the nuclear power program of Ontario Hydro be replaced with formal agreements.

3.6 There be agreements between A.E.C.L. and Ontario Hydro relating to the sale by A.E.C.L. of designs, drawings, reports and manuals of Hydro's nuclear generating stations.

STRATEGIC RESOURCES

3.7 Formal steps be taken through contractual arrangements to ensure that Ontario Hydro has an assured supply of natural uranium to meet the potential requirements of its nuclear power program, up to at least the year 2000.

3.8 *Appropriate steps be taken to ensure that adequate heavy water is available in time to satisfy Ontario Hydro's planned CANDU nuclear program and to support the further commitment of CANDU reactor in Ontario and elsewhere.*

3.9 *Ontario Hydro give consideration to constructing and operating heavy water production facilities adequate to assure its own supplies.*

3.10 *Ontario Hydro support the design, construction, and operation of CANDU reactors outside its own system by making available on reasonable terms experienced personnel but not to an extent that would prejudice its own nuclear power program.*

3.11 *Ontario Hydro explore the possibility of joint ventures with private enterprise to further other sales of CANDU.*

3.12 *Ontario Hydro arrange annual briefing sessions to inform industry concerning its nuclear power program.*

DEVELOPMENT OF FOREIGN MARKETS

3.13 *The Federal Government be urged to expand its campaign to sell CANDU reactors in Canada and abroad making use of all resources available not only within its own jurisdiction but also those in Provincial Governments and the private sector.*

3.14 *The Federal Government be urged to examine the feasibility of offering long term fuel and heavy water supply contracts to foreign purchasers as an added incentive to buy CANDU reactors, subject to a requirement for security of domestic supplies and present commitments.*

EDUCATION AND INFORMATION:

3.15 *Programs in applied science and engineering related to nuclear technology be established in selected universities and colleges within Ontario.*

3.16 (a) *Ontario Hydro's Nuclear Training Centre offer selected employees of Canadian utilities and the Canadian nuclear industry short courses of two to four weeks duration in nuclear power technology, with special reference to CANDU systems.*

(b) *The possibility of the Nuclear Training Centre becoming part of the Ontario educational system be considered.*

3.17 *To enhance the detailed knowledge of senior government personnel and industrialists with respect to nuclear power generation and to encourage dialogue between policy makers and nuclear scientists, short symposia be sponsored and organized by the Provincial Government and Ontario Hydro.*

3.18 *Ontario Hydro assume the initiative in the design and implementation of a major and sustained public information program related to nuclear power generation in order to improve the public's knowledge of nuclear technology and enhance its appreciation of the importance to the economy of Ontario of the effective exploitation of nuclear energy.*

APPENDIX I

TASK FORCE HYDRO
MEMBERS OF THE STEERING COMMITTEE

CHAIRMAN

J.D. Muncaster
President and Director
Canadian Tire Corporation Ltd.

H.A. Crothers
President
Crothers Limited

R.M.Dillon
Professor of Engineering Science
University of Western Ontario

A. Frame
Past President
Ontario Municipal Electric Association

H.S. Damp
Secretary

D.J. Gordon
General Manager
The Hydro-Electric Power Commission of Ontario

J.K. Reynolds
Deputy Provincial Secretary for Resources Development

R.B. Taylor
Vice President
The Steel Company of Canada Limited

CENTRAL STAFF

R.M. Dillon
Executive Director

J.B. Smith
Research Director

J.O. Beaulieu
Research Analyst

B.A. Baxter
Administrative Assistant

C.A. MacFarlane
Secretary

V.J. McAfee
Administrative Terminal Systems Operator

APPENDIX II

TASK FORCE HYDRO
NUCLEAR POWER PROJECT TEAM

Project Director	
P. A. Lapp	President Philip A. Lapp Limited
J. O. Beaulieu	Research Analyst Task Force Hydro
S. W. Clarkson	Executive Director Advisory Committee on Energy
R. M. Dillon	Executive Director Task Force Hydro
W. G. Morison	Assistant Director Generation Projects Division Hydro-Electric Power Commission of Ontario
A. Porter	President, Arthur Porter Associates Limited
J. Shantora	Research Analyst Task Force Hydro
I. W. Thompson	Philip A. Lapp Limited
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